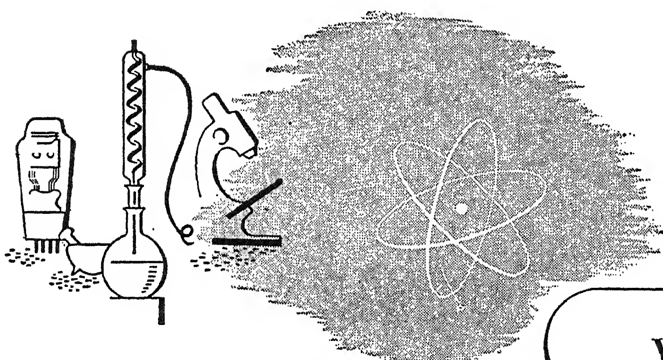
U. S. Army photo, from Acme

Atomic energy unleashed — an atom blast.

THE BOOK OF

POPULAR SCIENCE



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CONTENTS OF VOLUME IV

THE ISLANDS OF THE MAIN

In What Way Did the Sterile Islands of the Loneliest Seas Become Fertile and Inhabited?

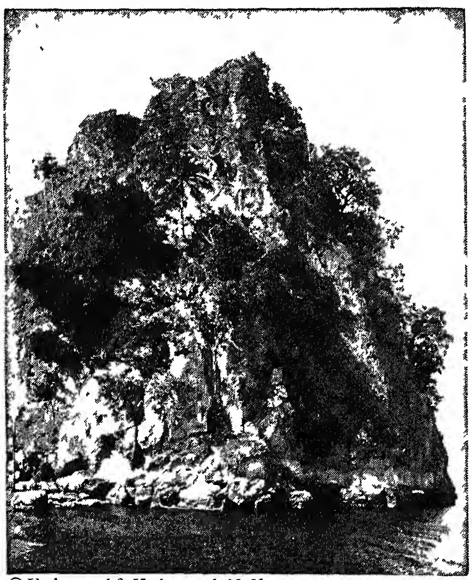
HOW THE PACIFIC ISLANDS WERE FORMED

ISLANDS are usually divided into two classes — continental islands and oceanic islands. Continental islands are islands that have formerly been joined to continents. They are the unsubmerged portions of the continental shelves, these shelves being the continental edges lying under water at depths usually not greater than 600 feet. Oceanic islands are islands that spring from the bottom of the ocean, and have always been insular, isolated and self-contained. Both continental and oceanic islands may be formed by destructive and constructive forces. Many well-known examples of the first type, formed by the submergence of an irregular shore line and erosive wave action, lie along our Atlantic Coast. Long Island, Block Island, Martha's Vineyard, Nantucket and Mt. Desert belong to this class. Sardinia, Corsica, Nova Zembla, Ireland and England are continental islands, for they were formerly continuous with the continent of Europe. Madagascar is a continental island, for it was formerly continuous with the continent of Africa. Ceylon is a continental island, for it was formerly attached to the continent of Asia. Tasmania is a continental island, for it was formerly part of the continent of Australia. New Caledonia and New Zealand are continental islands of a special type, in that the continental masses of which they once were part have subsided below the sea.

The largest continental islands are New Guinea, 312,000 square miles; Borneo, 290,000 square miles; Madagascar, 227,000 square miles; and Sumatra, 161,000 square miles. In some cases there is only a shallow channel of recent origin between continent and island. Between England and Europe, for instance, there is only a shallow channel of quite recent origin; and a fall of the sea level or a rise of the land level of a few hundred feet would wed again continent to island. In other cases, as between Madagascar and Africa, there is a deep channel of very ancient origin. But it matters not how deep, or wide, or old the severance between continent and island may be, in all cases, if the island was at any time part of a continent, it must be considered a continental island. By the same destructive action of waves and submergence, smaller islands may be formed from the larger ones, like the islands off the west and north coasts of Scotland.

Continental islands formed by constructive forces are mainly low sand islands thrown up as barriers such as the many sea islands along the Jersey coast, and lower down off North Carolina, two good examples being Capes Hatteras and Fear. Some oceanic islands may be looked on as the result of destructive forces. The Fiji, for instance, a group of 255 islands, large and small, in the southern Pacific, and Spitzbergen, a numerous cluster in the Arctic Ocean, are only fragments of larger parent masses. Most oceanic islands, however, are the result of constructive forces and naturally group themselves in two classes, volcanic islands built up from the sea bottom by igneous agency, and coral islands produced mainly by coral polyps growing on submarine ridges or submerged mountain peaks.

Volcanic islands are found widely dispersed, but always in regions of volcanic activity Often, as in the Aleutian Islands, the Kuriles and Philippines, they form chains, but in other cases they occur singly. Our Territory of Hawaii is a fine example of the former. It consists of a chain of eight inhabited islands and several rocky points in the Pacific, about 2000 miles southwest of San Francisco, extending from the island of Hawaii 390 miles northwest to Niihau. These islands are really the peaks of a submarine volcanic ridge pushed up from the ocean floor through three miles of sea.



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A ROCK FLUNG UP OFF NEW BRITAIN BY A VOLCANIC DISTURBANCE

Since the oceanic islands were never connected with continents, their flora and fauna must have been imported. Only birds could reach them, and such animals and seeds as might be carried to them by floating logs and other driftwood. Accordingly, both their fauna and flora are rather restricted.

Though the least important, the most interesting of all islands are the coral islands, for their mode of origin and their setting in the azure southern seas both make a great appeal to the imagination. Let us therefore look for a moment at the manner of the making of coral islands.

We have already noticed how chalk and limestone have been built up of the shells of foraminifera, which in the first place accumulated on the ocean floor. Many other shells go to the making of limestone rocks The oyster-shell beds which are found as regular banks in certain parts of the sea, the accumulations of the shells of sea-urchins and stalked starfishes, the coralline algæ — in fact, the stony remains of all animals with the power of extracting calcium salts from sea-water, are material for future mud But of all the builders that make limestone rocks, none are more active and more effectual than the coral polyps which build islands and ramparts of snowy stone in the waters of the sea.

The coral polyps are cousins of the sea-anemones, and they resemble the latter in certain ways. They have little, baglike bodies and they have a circle or a series of circles of little arms or tentacles round their mouths just like sea-anemones, but they differ from sea-anemones in that they secrete carbonate of lime, and form a kind of cup-like skeleton which remains behind after the death of the animal It is quite probable that the tiny animals absorb the calcium sulphate of the sea-water and convert it into the carbonate. This limestone secretion is known as coral.

There are many species of coral polyps, such as astræa, porites, madrepora, millepora, and each has its own characteristic skeleton. In some cases the coral polyp multiplies by successive budding so that eventually there is a structure of coherent polyps, and the skeleton that results is the branched coral which is so familiar. In other cases a similar budding takes place, but the buds are all compacted together, and the resultant skeleton takes the shape of a giant head, one variety, Meandrina, being called the brain coral on account of its deeply furrowed surface. The madrepores, or staghorn, and the brain corals, are the main reef builders. But it must not be supposed that a coral growth is merely a charnel heap of skeletons, a whited sepulcher. Above low water it is dead, beneath the thirty-fathom line it is dead, but sandwiched between the skeletons there is a colony of millions

and millions of delicate living creatures — a "submarine flower garden" of living, quivering, multiplying anemones, each with its circlet of subtle and sensitive tentacles.

We find coral polyps in all oceans from sea level to a depth of two miles; on the east coast of North America 14 living species have been found, some as far down as 6000 feet. But the corals that build reefs and islands are very particular in their tastes, and inhabit only warm and clear seas where there are no cold currents, where the mean temperature of the air is not lower than 63° F, and where the mean temperature of the sea is not below 68° F. They do not live near the mouths of great rivers, because of the muddy water; they shun the Somali coast, because the southwest monsoon causes ascending currents, and they avoid the west coast of South America, because of its muddy sea and the cold polar current that flows along it; but they flourish in the Red Sea, the Persian Gulf, the Gulf of Mexico, the western Indian Ocean; and in the Pacific, their favorite habitat, there are no fewer than 290 coral islands. The Gulf Stream makes life possible for them even in temperate zones, and there are coral islands and reefs as far north as the Bermudas.

ISLAND WITH BARRIER AND FRINGING CORAL REEFS

But the reef-building polyps require more than climatic advantages; it has been found that they never live below thirty fathoms nor above low-water mark, and this, of course, greatly restricts their reef-building operations. Nevertheless, in spite of all restrictions, the reef-building polyps have done an amazing amount of work in distant geological times as well as in modern eras. Coral reefs dating from the Middle Silurian are found in Wisconsin and Kentucky. And though coral islands and reefs, as a rule, are small, the total area covered by coral is surprisingly large. The Great Barrier Reef of Australia alone measures 33,000 square miles — enough to cover quite two-thirds of the State of New York.

The massive formations of coral may be divided into three classes: (1) fringing reefs; (2) barrier reefs; (3) atolls

Fringing reefs are comparatively small reefs that border islands and continental coasts, quite close to the shore, and are separated from it only by shallow water On their seaward side the water is deeper, but still shallow, and the sea floor slopes gradually downwards. Our nearest fringing reefs line the Florida coast; they are also found off Mauritius Ceylon, the Nicobar Islands, the West Indies, and in the Red Sea

Barrier reefs lie in the same situations off islands and continents as fringing reefs, but they are more massive, farther from land, and with deeper water both on their seaward and landward sides. So deep, indeed, is the water on the seaward side of these reefs that it used to be considered unfathomable. When the barrier reefs surround islands the reefs are known as "encircling barrier reefs", and the island in the center as a "lagoon island". Many of the South Sea Islands, the Fiji Islands, the Society Islands, the Solomon Islands, Samoa, New Caledonia, etc, are circled by reefs, and within the reefs is a natural harbor to which entrance can be gained only through breaches in the barrier. It must be noted that the mere addition of fringing or barrier reefs to an island gives it no right to be called a coral island. Barrier reefs are always low, rarely more than ten feet high, and are narrow in proportion to their length. A reef off the west coast of New Caledonia has a total length of 400 miles, and its distance from land varies between eight to sixteen miles. The Great Barrier Reef, off the northeast of Australia, is nearly 1250 miles long, and has a breadth of ten to ninety miles. It is from twenty to seventy miles from land, and on its seaward side the water is in places as much as 1800 feet deep. Fringing reefs and barrier reefs are in connection with land, but atolls are irregular circlets of coral quite isolated from land.

Atolls may be in the form of a crescent, or a circle or a horseshoe. They may be very much broken up; in that case, an atoll looks like a chain of islands. Atolls of circular shape enclose shallow lagoons of beautifully clear water. Sometimes the lagoons are entirely cut off from the sea; more often there are channels that allow entrance into the lagoon. Such lagoons make magnificent harbors; for though in storms the waves break over the reef, the center of the lagoon remains smooth. Some lagoons are a hundred miles across; and there is within their broad expanse "accommodation for all the navies of Christendom to ride at anchor."

The sea is usually deep outside atoll reefs

Outside the atoll reef, the sea is usually very deep. At a mile and a quarter seaward of the small coral islands of the Cocos, or Keeling group, soundings of 7,200 feet have been taken. Like other reefs, atolls never reach a height of more than twenty feet or so. The Maldive, Laccadive and Chagos islands, in the Indian Ocean, are among the most typical atolls. The small island of Swains, in the American Samoa group, offers a fine example of an atoll with a lagoon completely shut off from the sea. In atoll lagoons many different kinds of marine animals are found. Most atolls are more or less covered with tropical vegetation.

How the atolls of the South Seas obtain soil

It may be wondered how these islands obtain soil. Some of it is obtained from the droppings and the dead bodies of sea birds; some from decaying vegetable matter, sand and pumice stone washed up by the sea. Strangely enough, the land crabs that inhabit most of the islands play a very active part in the accumulation and cultivation of the soil. In certain islands there are hundreds and thousands of these land crabs constantly scouring the beach and collecting twigs of trees, seaweed and scraps of coconut to bury in their burrows. Other crabs are continually engaged in burying coconuts and seeds and vegetable matter in the soil. Some crabs industriously turn over the soil; others excavate tunnels in the ground and line them with coconut fibers. Thus the waves and the birds and the crabs together manage to change the stony surface of the reef into a dark, rich vegetable mold.

How plants and animals are brought to atolls

Seeds reach atolls from land areas in various ways. Birds sometimes carry them in their crops or attached in some way or other to their feathers or their feet. Other seeds, such as coconuts, are frequently washed ashore. Eggs of various reptiles and other animals are brought on drifting trees; men may arrive in ships and canoes. In time, accordingly, an atoll gets a flora and fauna and becomes a habitable island — a sort of oasis in the boundless deep.

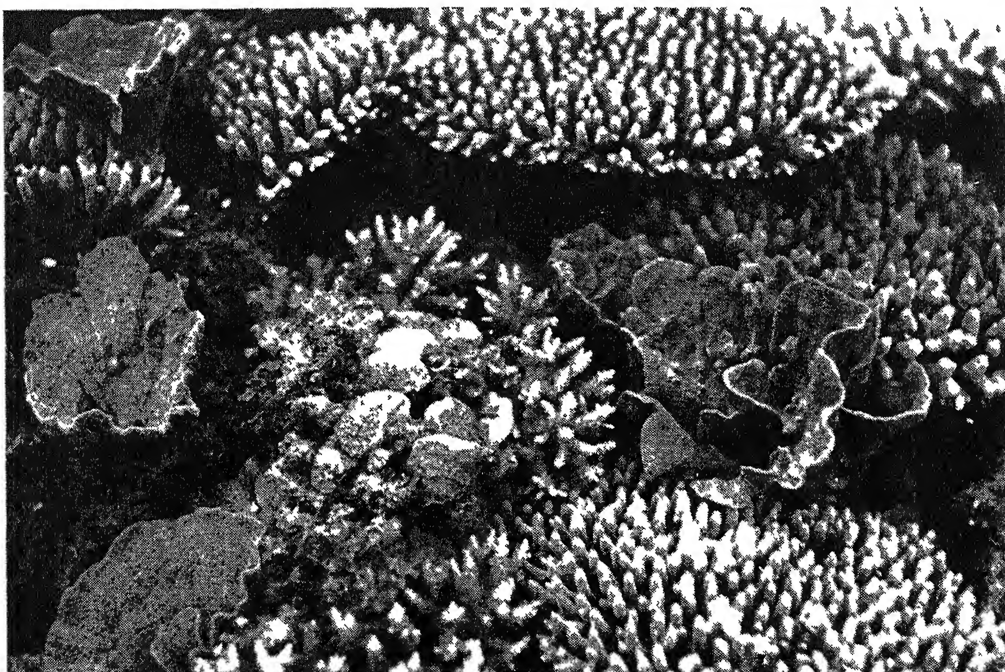
A typical atoll of the South Seas

The English geologist W. J. Sollas thus described his arrival at Funafuti, one of the Ellice Islands, situated in the middle of the Pacific to the north of Fiji: "The ship was steered for the southern entrance; this was safely made, and we steamed into the noble lagoon. Flying fish spurted from under our bows and zigzagged in their darting flight around us; here and there in the midst of the blue waters green and purple shallows marked the site of growing coral patches. On the starboard side lay the beautiful island of Funafuti proper, its pale sands ablaze in the light of the tropical sun, its groves of palms cool with a refreshing green. A boat put off from the beach, manned by a crew of copper-colored natives, their black hair crowned with wreaths of gardenia and hibiscus flowers. They were soon swarming over our sides, bringing with them the solitary white trader of the island, who safely piloted us to anchor within a mile of the shore. Captain Field and a party immediately landed, and we went at once to pay our respects to the king, who, notwithstanding the narrow limits of his realm and the smallness of his nation, which numbers all told only some two hundred and forty souls, we found to be every inch a king."

Much of the island, as W. J. Sollas described it, is covered with coconut palms and other trees, and there are numerous ferns and brightly colored flowering plants. Other coral islands are equally fertile. Whitsunday Island, off the east coast of Queensland, Australia, is covered so thickly with a luxuriant tropical vegetation that no soil can be seen. It is marvelous that these circles of snow-white rock, springing up like fairy rings in the middle of the sea, should succeed in obtaining soil and plants and animals in the way we described.

are broken off, and piece after piece is hurled inward. The fragments are wet with water holding calcium carbonate in solution; as the water evaporates, this potential limestone crystallizes, binding the broken fragments into solid coral rock above the growing reef.

This explains the height of coral above sea level, but how do we explain the great depths from which coral upbuilds? Reef polyps will neither build above water nor deeper than thirty or forty fathoms, and they do not flourish abundantly below six



Australian News & Information Bureau

Flowers of the South Pacific seas — magnificent coral formations on Australia's Great Barrier Reef.

We have said that coral islands are almost invariably low islands. Our nearest examples, in civilized garb, too, are the Florida Keys, a two-hundred-mile chain, with Key West as its best-known link. The average height of the Keys above sea level is only eleven feet. But coral does rise to a height of twenty feet above the sea, and we must inquire how it comes to rise above the water at all, when the coral polyps can work only under water. The outer edges of the reefs, catching the pounding fury of the storm-driven waves,

or seven fathoms. How, then, can coral atolls rise out of the deep sea? To solve this problem Darwin proposed an interesting theory, which Dana, an American geologist, adopted and elaborated. Darwin suggested that atolls were originally fringing reefs that circled islands. The islands slowly subsided, and as they subsided the reefs grew upward and outward and became barrier reefs, provided that the rate of submergence was not greater than the upward growth of the corals. Finally, the islands subsided altogether, and the

barrier reefs, still continuing to grow upwards, became atolls. According to this theory, each atoll is "a garland laid by the hand of nature on the tomb of a sunken island". Of these islands we have no record, but Reclus states that the natives of the atolls of Ebon say that their fathers remembered a time when an island with cocoanut palms and bread-fruit trees occupied much of the center of the lagoon.

When we consider how many atolls and barrier reefs there are, and the huge extent over which they are scattered — an area in the Pacific Ocean measuring fully 6000 miles from east to west, about 1000 to 1500 miles from north to south — it is evident that Darwin's theory postulates a great instability of the ocean floor; but there is nothing incredible about the postulate, especially since the coral reefs are almost always in volcanic areas and associated with volcanoes, which themselves are signs of instability, and for a time Darwin's subsidence theory met with acceptance. But soon difficulties became apparent.

The difficulties in the way of Darwin's subsidence theory

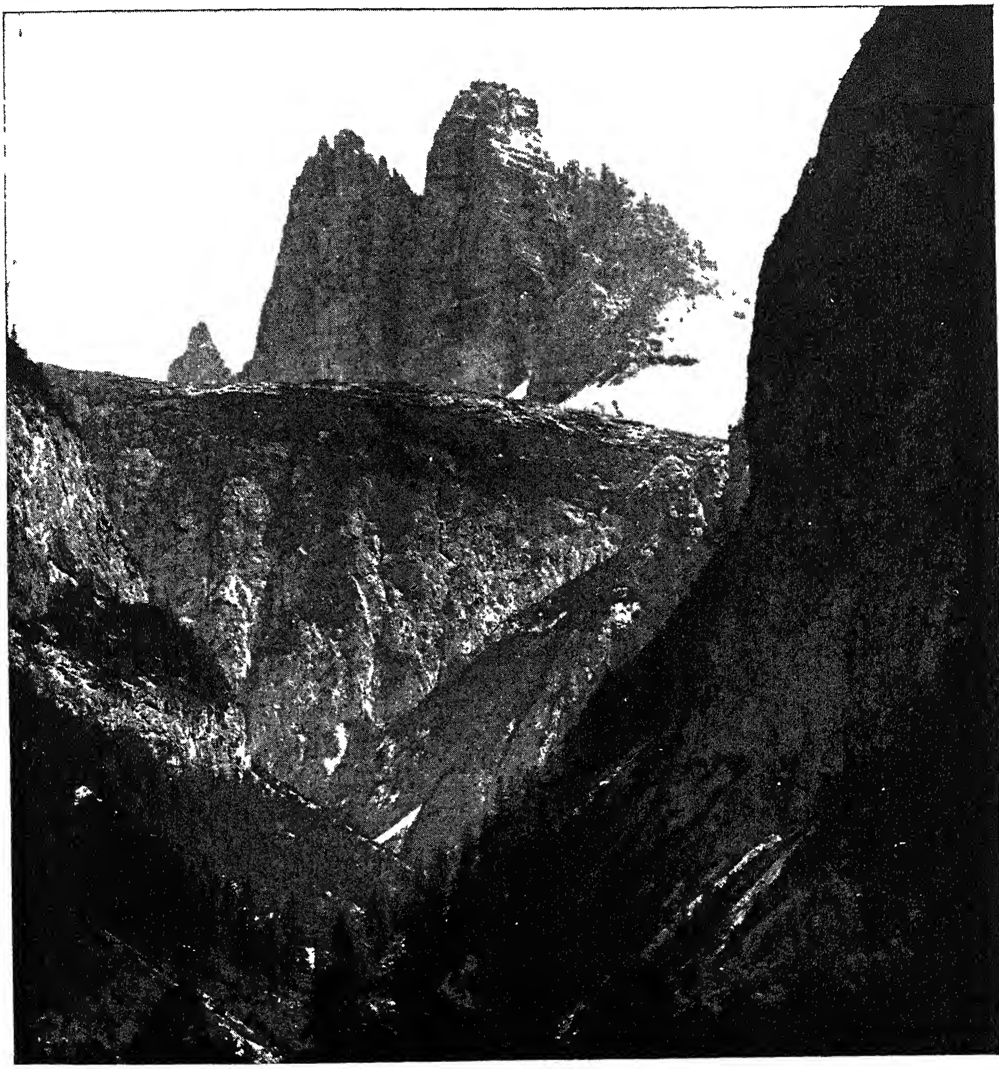
In the first place, it was pointed out that if coral were formed in the sea in such mountainous masses, it was a strange thing that no part of the ocean floor which had been upheaved showed any such immense coral formation. Then it was found that atolls and raised coral reefs may occur within fifty or sixty miles of each other, and in the Solomon Islands there are raised coral reefs of all heights from 100 to 1200 feet. In view of these and other difficulties, Sir John Murray and Alexander Agassiz advanced another theory which has gained a great deal of acceptance. The Murray theory is one of elevation and solution, and it considers that subsidence has very little to do with the characteristic forms of coral reefs. It maintains that the coral polyps founded their colonies on the summits of volcanic mountains when these rose to a suitable height from the bottom of the sea. Seeing that reef builders will grow only at depths between sea level and the thirty or forty fathom line, and will really thrive only six or seven fathoms down, this theory would seem to require an extraordinary and most unlikely uniformity on the height of the submarine volcanic mountains that are the foundations of atolls. But the Murray theory does not assume that the submarine mountains which are elevated from the sea floor all reach the same height. It merely assumes that *when*, in the course of their upheaval or in the course of their denudation, they reach a certain height, then the polyps find them a suitable platform for building, and proceed to build. If the peak or platform on which they build continue to rise, they will eventually be lifted, as in the case of the reefs we have mentioned on the Solomon Islands, high above the sea If the peak subside slowly, then they will build upwards, and maintain their colony at a liveable level.

The difficulties in the way of Murray's theory of elevation

Further, it is not necessary that the peaks should actually themselves rise to the suitable height. Even supposing, as is very likely, that the submarine peaks rise to varying heights, yet those above the right height will be pared down by submarine denudation, and those below the right height will be built up by sedimentation. All the coral islands in the regions of globigerina ooze rise from water teeming with foraminifera; and if on the bottom of the sea calcareous sediment accumulates to the depth of thousands of feet, likewise it must accumulate on the submarine peaks, and gradually raise them to a height within reach of the coral polyps. Professor Joly holds that those areas of the ocean bed where sediment is thickest are just those parts which are softest and weakest, because of the heat produced by the radioactivity of the sedimentary material. Accordingly, there the earth's crust buckles under volcanic force, and we have ridges and volcanoes which are still further raised by a rain of foraminifera. It is a pretty theory—the volcanic mountains raised by the agency of tiny shells, and still further heightened by the remains of other calcareous organisms till they are high enough to serve as a platform for atoll reefs.

On the top of the peak or elevated plateau there would be first globigerina ooze, then pteropod ooze, then remains of starfish, deep-sea corals and other calcareous organisms, and, finally, the coral material

All this certainly offers a reasonable explanation of the rise and emergence of coral atolls, and of the height above sea level at which coral occasionally is found; but how does Murray explain the shape of atolls? The coral polyps, according to Murray, build at first a flat table of coral rock. As this table thickens and grows upwards, its rim increases most rapidly, because the polyps situated there are more exposed to the ocean currents, and have therefore the most plentiful food supply. The result is that the upper surface of coral, instead of being flat, becomes concave or saucer-shaped The rim of the concavity further hinders the flow of currents with food supply towards the center, and finally when the rim rises above water, it cuts off food supply from the center altogether. The result is that the central coral polyps die and their coral, like dead teeth, softens and breaks down and dissolves, and is scoured out by the sea.



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MOUNTAINS OF TODAY MADE BY LIFE BENEATH THE SEA — THE DOLOMITE DREI ZINNEN

Further, as the margin steadily grows outward, the central part, *pari passu*, is dissolved away, and so the atoll grows larger and larger till its lagoon may measure a hundred miles across. The solution of the coral in the lagoon is much assisted by the carbonic acid gas added to the water of the lagoon by accumulations of decomposing seaweed. In a similar manner a fringing reef will become a barrier reef by rapid increase of its outer surface, and death and dissolution of its landward side.

According to Darwin's theory, the atoll is "a garland laid by the hand of nature on the tomb of a sunken island". According to Murray's theory an atoll is "a wreath of victory crowning a youthful summit on its first conquest of the main".

It occurred to Professor Sollas that the matter might be settled "by sinking a bore-hole through some well-characterized atoll, and thus obtaining specimens of the material of which it is composed down to a depth considerably greater than that at which corals are supposed to build". If the Darwin-Dana theory be correct, coral substance should extend down far below the life-limits of the coral polyps; if the Murray-Agassiz theory be correct, then layers of chalky ooze should begin at a depth of thirty or forty fathoms.

Professor Sollas organized a coral-boring expedition, obtained the loan of a diamond drill from the government of New South Wales, and proceeded to Funafuti, the atoll we have already mentioned. After several unsuccessful attempts a core was finally cut out to a depth of 1114 feet.

The material obtained was cut into nundreds of thin, transparent slices, and subjected to careful microscopic examination by an expert; and the following conclusions were reached: "(1) The limit of reef-building growth does not exceed, if indeed it reaches, a depth of 45 fathoms below the level of the sea; (2) true reef-rock was passed through in the boring from the surface down to 185 fathoms; (3) no rock other than reef-rock was encountered, and in particular no Tertiary limestone; (4) the structures met with were such as to exclude the notion that the reef had grown upwards on talus of its own *débris.*

"From these inferences but one conclusion appears possible, and we must admit that this atoll at least has been formed during a subsidence of the foundation on which it rests, a subsidence which must amount to at least 877 feet."

The result, then, of boring the reef was to support the theory of Darwin and Dana rather than that of Murray.

Quite recently Professor Daly of Harvard has introduced a new idea into the theory of barrier and atoll growth. The enormous accumulation of ice during the glacial period, millions of square miles in area and thousands of feet thick, lowered the equatorial seas probably 250 feet. By the cold coral life was restricted to very narrow tropical belts. Elsewhere the oceanic island shores, unprotected, were cut into terraces or the islands themselves reduced to sea level by the beating waves. As the Ice Age passed, the melting ice raised the water level, the seas grew warmer, and on the eroded shelves and island platforms flourished the returning reef-builders. This would account for the almost uniform 250-foot depth of reef platforms and lagoon basins.

The question of the exact manner of the making of atolls may seem a very small one, but, like many other apparently small scientific problems, it may have large connections. The history of the atoll is part of the history of the ocean floor, and therefore of the history of the earth's crust; and a study of coral formation and even of coral chemistry may elucidate many geological problems. For instance, in the course of the investigation we have mentioned, it was found that the deeper coral limestone contained as much as 40 per cent of magnesium carbonate, and that a calcareous alga was distributed over the floor of the lagoon. Now, the dolomite peaks of Tyrol are found also to contain a large percentage of magnesium carbonate, and to have calcareous algæ in their composition; hence the view that they were once coral reefs receives confirmatory evidence. The changes of those splintered peaks are not less dramatic than that imagined by the poet who saw how

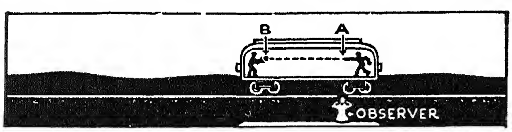
> Where the long street roars hath been
> The stillness of the central sea.

THE THEORY OF RELATIVITY

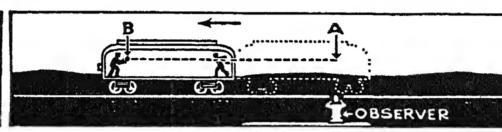
The Modern Concept of Time,
Space and Motion

THE NEW LAW OF GRAVITATION

THE modern "Theory of Relativity" has to do with the problem of motion, which greatly interested philosophers from the beginning. The view developed by the Greeks had been refined by Newton into the conception that motion consisted primarily of a change of position in "absolute space". Such positions being, however, in practice indistinguishable from each other, only motion relative to some other physical entity, such as the earth, can actually be detected. Newton showed, in fact, that the laws of mechanics remain unaltered if the entire system involved is given a motion of uniform translation; for instance, if a game of billiards is played on board a smoothly moving ship, the balls move over the table and rebound from the cushions in just the same way as they do when the table is at rest on the land. Or, stated in technical terms, the laws of mechanics are the same when referred to either of two "frames of reference" which are undergoing a motion of uniform translation relative to each other. Rotatory motion of an extended body, such as the spinning of the earth on its axis, can be regarded as motion of the parts of the body relative to each other, but closer analysis of the fundamental distinction between rotation and pure "translation" reveals in this distinction an element of absoluteness whose true nature remains still somewhat obscure.



A man in a moving train throws a ball from the rear of the car to be caught by a friend at the front end. To him it seems to move just as it would if the car were at rest; it travels 40 feet, the length of the car, in one second.



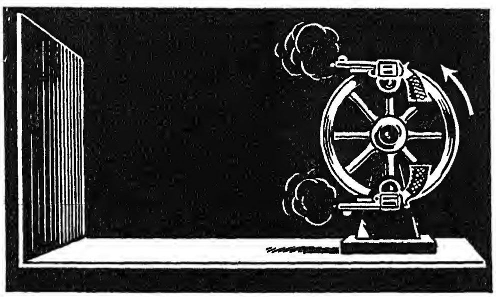
At the same time an observer sitting beside the track sees the ball moving both with the motion of the train and the motion imparted by the throw. He finds that it has gone, when caught, 40 feet + 60 feet (the train's speed per second) in one second.

The theory of motion remained in this state until about 1830, when a great change occurred following the establishment of the wave-theory of light. It is characteristic of waves in general that they move with definite speed through the medium conveying them; it would be expected to follow, therefore, that the speed of light-waves traveling in the ether is always the same relative to the ether and is different relative to bodies which are themselves moving through the ether. As a parallel instance, the speed with which a water-wave passes a moving boat is certainly different from the speed of the wave over the water. It was not until 1885, however, that an experiment was devised capable of revealing an optical effect of this kind and so capable of detecting, for instance, the motion of the earth through the ether. In this experiment, performed by Michelson and Morley in America, the mean speed of light going back and forth along one direction was compared with its mean speed in a perpendicular direction. If the first of these two directions were

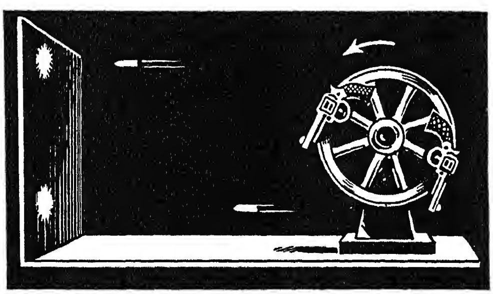
The illustrations in this chapter, except the portrait of Professor Einstein, are from the film "The Einstein Theory of Relativity", by permission of its distributors, Multiphone Corporation of New York.

made parallel to the earth's motion in its orbit around the sun, and if the sun happened to be stationary in the ether, then the mean speed of the light relative to the apparatus should be less in that direction than its mean speed in the perpendicular direction by about one part in 200,000,000. So small a difference could easily have been detected with the apparatus employed; *but it was not found.*

A very simple explanation of this negative result would be obtained if we could suppose that the light employed by Michelson and Morley, which came of



The pistols are discharged while the wheel is in rapid rotation.



The light flashes, both moving with the same speed, have already reached the target together The upper bullet, however, will arrive ahead of the lower one

course from a lamp stationary on the earth, had the velocity of the lamp and therefore of the earth added to its own natural velocity of propagation, just as a shell fired from a moving battleship has the velocity of the ship added to its velocity of projection from the gun. There are, however, good experimental reasons for believing that such was not the case; the velocity of light, in harmony with the requirements of the wave-theory, is quite unaffected by the velocity of the source that emits it, just as sound from a moving engine-whistle is propagated at the same speed through the air as is sound from a stationary whistle

In one sense of the word no satisfactory explanation of the result of Michelson and Morley has been discovered to this day. In 1907, however, the whole subject was given an entirely different aspect by a bold speculation due to A. Einstein, which has become known as the "Restricted" or "Special Theory of Relativity".

The Special Theory of Relativity

Instead of multiplying explanations of our numerous failures to devise an experiment for detecting motion through the ether, Einstein proposed simply to adopt the view that nature was so constituted as to make the detection of such motion fundamentally impossible; or, put another way, motion relative to the ether is a meaningless conception. The ether is no more a thing that has recognizable parts and can be moved through than is, for instance, the President's opinion on the tariff, although both the ether and the presidential opinion may play large parts in the control of events. Many theorists nowadays regard such an attenuated ether as a useless conception; but this is a matter of preference.

As the basis of his new theory, Einstein laid down these two "postulates":

(1) *Postulate or Principle of Relativity. All physical laws are the same when statea in terms of measurements made in either of two frames of reference whose motion relative to each other is one of uniform translation, and these laws do not involve velocities relative to "space" or to the ether (if there is one).* (A "frame of reference" is simply a set of measuring rods and clocks, together with suitable base-points of reference, with which measurements of time and position may be made.)

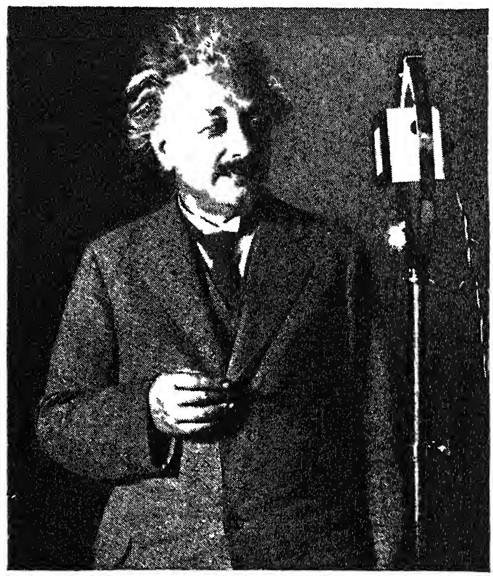
(2) *The velocity of light is unaffected by motion of its source.*

Both of these postulates are in harmony with all known facts, but if their consequences are traced beyond the reach of ordinary present-day experiment conclusions are arrived at which are remarkable and quite contrary to common experience It follows, for instance, that if a physicist working in a laboratory on a fast-moving

airplane were to measure the velocity of light relative to his apparatus on the airplane, he must obtain the same value for the velocity as would a physicist who worked in a laboratory on the earth and measured the velocity of light relative to apparatus in that laboratory. At first sight this seems as absurd as if a man on a moving railway train, upon measuring with a stop-watch the speed at which a race-horse swept past his train, were to obtain the same result as was found by the official timer for the speed of the horse over the ground (the correct result being, of course, that the speed v' of the horse past the train is given by the equation $v'=v-u$, where v = speed of the horse over the ground and u = speed of the train).

The explanation of this paradox, according to Einstein, lies in a point that was left obscure in Newtonian theory but which becomes of importance when we are dealing with such a fast-moving thing as light. Any measurement of the velocity of light in one direction must reduce ultimately to something essentially the same as the method of timing a straightaway race, namely, noting by means of two stop-watches or their equivalent the times of departure and arrival of a light-flash at the ends of a measured course. But it is then necessary to test the stop-watches in some way to see whether they read together. Now the common method of comparing time-pieces in distant places is by means of wireless signals; but for high precision, such as would be required in observations upon light itself, we should have to make a correction for the finite rate of propagation of the signal, which is the same as the speed of light or the very quantity we are trying to measure. Such a method thus lands us in a hopeless circle. An older method was to carry a chronometer from one place to the other and compare it with the clocks in both places; but it cannot be assumed without proof that the rate of going of a chronometer is the same when it is in motion as when it is at rest. The whole difficulty could be evaded if some kind of signal could be exchanged that required no time to pass from one place to another; but no such signal is known, and Einstein's postulate implies that there is some reason connected with the fundamental nature of the physical world why such a signal can never be invented.

If this is so, then there is no method whatever by which we can set clocks at different places in definite and indubitable synchronism with each other; we are reduced to the expedient of making an arbitrary convention about it, and the measured velocity of light in a single direction becomes a matter of convention and not a fact of nature Of course, the ordinary measurements of the "speed of light" are



Wide World Photos

PROFESSOR ALBERT EINSTEIN
in Berlin complimenting Thomas Edison in Detroit on his golden jubilee.

unaffected by the difficulty in question, since they refer always to the mean speed of a light-ray which travels to a distant point and back again; we are here trying to separate the velocities referring to the two halves of the journey. The question did not arise until recent times because experimental technique had not hitherto been sufficiently refined to make it of importance, and an essential characteristic of the modern scientist, as compared with the medieval or Greek natural philosopher, is that he thinks little about theoretical points having no bearing upon observed facts.

Accordingly Einstein proposed to adopt the convention that the speed of light is to be the same in any direction as it is in the opposite direction, thereby preserving the isotropy (the state of having the same properties in all directions) of space. The speed of light in free space becomes then a universal constant, which we shall denote by c. Having adopted this convention, we are prepared to deduce the relationship between measurements made with two different frames of reference each of which is in uniform translatory motion with respect to the other. The resulting formulas, known as the Lorentz transformation, are:

$$x' = \gamma\,(x - ut),\ y' = y,\ z' = z$$

$$t' = \gamma\,(t - \frac{u}{c^2}x),\ \gamma = \frac{1}{\sqrt{1 - \frac{u^2}{c^2}}}$$

in which t is the time and x, y, z are the Cartesian coördinates of the position in space at which an event occurs as measured in one frame of reference, t', x', y', z' are the same quantities when measured in the other frame of reference, and u is the velocity of the second frame relative to the first; for simplicity we have, following custom, chosen axes and zeros of time so that the x and x' axes always coincide, the velocity u being toward $+x$, while the y' and z' axes remain parallel to the y and z axes respectively and the two origins of coördinates coincide momentarily at time $t' = t = 0$. These formulas constitute the kernel of the Special Theory of Relativity. A few of the conclusions that can be drawn from them are the following.

For one thing, we see at once how it is that observers using two different frames of reference can always obtain the same value for the speed of light. They set their clocks differently: at a given time t, as shown by the clocks in one frame, the clocks in the other frame show different times t' according as their locations differ in the direction of x, i.e. in the direction of relative motion of the frames. It follows that observers using different frames may disagree as to whether two events happening at different places occur simultaneously or not; to one observer they may appear simultaneous, to another a certain one of the events may appear to precede the other, and to a third the second may appear to precede the first. According to Einstein it is impossible to say that any observer is "right" and the other wrong. For example, to a given instant of time at New York, say 3:00 P.M. exactly, there corresponds at San Francisco, not a definite instant, but an interval of about 1/45 of a second (the time taken by light for a double journey between the two places); any event happening within this interval at San Francisco occurs simultaneously with the striking of 3:00 P.M. at New York in some frames of reference, before it in others and after it in still others. *Thus the time-order of events at different places is in part a relative matter*, just as is the occurrence of events at the same place (in certain frames) but at different times. Instead of events differing in two clearly distinguishable aspects, namely, in spatial position and in position on the time-scale, as has always been assumed hitherto, their difference of location must be regarded from a more general point of view as a difference of location in four-dimensional "space-time". This implication of Relativity is perhaps the most important one as regards its philosophical bearing.

Consideration of the Michelson-Morley experiment from the new standpoint leads to another interesting conclusion. Since all frames of reference are equally valid, we may choose one on the earth in which the apparatus is stationary. Then the negative result of the experiment (equal speeds of light in all directions) requires no explanation beyond the isotropy of space. But it would be equally allowable to take a frame fixed with respect to the sun, and in this case the old problem arises again, except that now it is not the ether but the reference frame relative to which the apparatus is moving because of the earth's motion along its orbit. From the point of view of such a frame the explanation of the experimental result lies in the following property of the lengths of moving objects.

A moving object cannot be measured simply by laying a yardstick upon it unless we know what effect the motion may have upon the yardstick. The simplest pro-

cedure is probably to define the length of a moving object as the distance between two points, fixed in our frame of reference, which are passed by the ends of the object at the same instant. It can be shown that any other method of measurement such as photography (with allowance for errors due to the finite speed of light) will yield the same result. From the Lorentz formulas it then follows that if a body is moving with speed v and if L is its length or width in the direction of its motion, and if L_O is the same linear dimension as measured in a second frame (moving relative to the first) in which the body is at rest, then

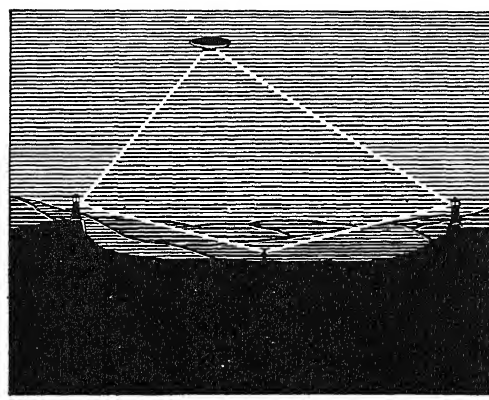
$$L = L_O\sqrt{1-\frac{v^2}{c^2}}$$

(To obtain this result, we put $t=t_1=t_2$ and $L=x_1-x_2$, $L_O=x_1'-x_2'$, $u=v$.)

Thus moving bodies undergo a sort of contraction in the direction of their motion (the Lorentz-Fitzgerald contraction); their length L_O as measured in "their own" frame, i.e. their "proper length", does not change, yet the effect upon their surroundings is in all respects the same as if they had really contracted. For instance, if a row of airplanes standing nose to tail were to take flight together and attain half the speed of light, gaps of a seventh of their length would form between them and the sun would shine through these gaps. We have here a kind of "kinematical perspective"; bodies in relative motion bulk less large in each other's worlds, much as do any two objects as they recede from each other, although in a certain sense the objects themselves remain unchanged. The contraction is, unfortunately, very minute at speeds obtainable in the laboratory; even at the earth's orbital speed of 17 miles a second it amounts only to 2.5 inches in the whole diameter of the earth. Besides the Michelson-Morley experiment, this contraction serves to explain one electrical experiment (Trouton-Noble).

A similar "perspective" effect is predicted by the theory as regards time. If two systems are in relative motion, all natural processes in one of them must go on more slowly as judged in the other in the ratio, $\sqrt{1-u^2/c^2}$. In this case, however, the effect can be made cumulative; for instance, if a man were to travel at high speed round a large circle, when he got back to the starting-point his watch would have lost as compared with a stationary one, and he would have breathed fewer times and turned less gray than did his friends who remained at home. There is no experimental evidence at present either for or against this rather bizarre conclusion.

The majority of physical laws require some slight alteration to make them invariant under the Lorentz transformation and so consistent with Relativity. In Mechanics, the fundamental laws of the Conservation of Energy and the Conserva-



Both towers flash together. The observer on the ground reports simultaneous flashes. The observer in the balloon claims that the left-hand tower flashed first.

tion of Momentum can be preserved but only if we suppose the mass of a moving body with speed v to increase in the ratio $1/\sqrt{1-v^2/c^2}$. Such an increase has actually been found in the case of electrons, but here it finds a ready explanation in terms of classical electromagnetic laws and was actually predicted from them before the days of Relativity. The kinetic energy T of a moving body can then be written (in c.g.s. units)

$$T=c^2\,(m-m_O),$$

where m is its mass while moving and m_O its "rest-mass" or mass when at rest; the classical value, $T=mv^2/2$, is a first approximation for small values of the speed. We could also write:

$$m=m_O+\frac{T}{c^2}.$$

In this form the equation suggests that the increase of mass may itself be due to the addition of energy; perhaps, even, it is energy that possesses mass and not matter as such; perhaps a body at rest possesses a mass m_0 only because it possesses internal energy of some sort of magnitude c^2m_0. If this is so, then a quantity E of light energy should possess mass of amount E/c^2, and, since it is moving with speed c, it should also possess momentum of amount E/c. This conclusion as to momentum has long been known to state a true fact, for light falling upon a body exerts a slight but measurable pressure upon it exactly in accordance with this result (just as a shower of hail exerts a pressure upon a roof because of the momentum of the falling hailstones). Recently it has been demonstrated by experiment that a light quantum of sufficient energy can be converted into matter: an electron and positron. Conversely, an electron and positron can combine and be converted into light of energy equivalent to the mass of the two particles. Measurements show agreement with Relativity.

There is one group of physical laws which requires no modification, namely, the laws of electromagnetism. The magnetic effects of moving electric charges or currents represent, in fact, that correction upon Coulomb's law for the attraction and repulsion of electric charges which is required in order to secure harmony with Relativity.

The few experiments that it has been possible to make upon the minute effects predicted by the theory, combined with the fact that electromagnetism fits in so well with it, have convinced nearly all theoretical physicists of its truth. The Special Theory of Relativity must still be regarded, however, as a bold speculation which may one day be found to require further correction. Doubtless the great interest that it has aroused has been due in chief measure, not to its actual accomplishments, but to the striking demonstration associated with it that our ideas of space and time were, after all, capable of radical change and might very likely have to be revolutionized in order to bring them into harmony with the behavior of nature.

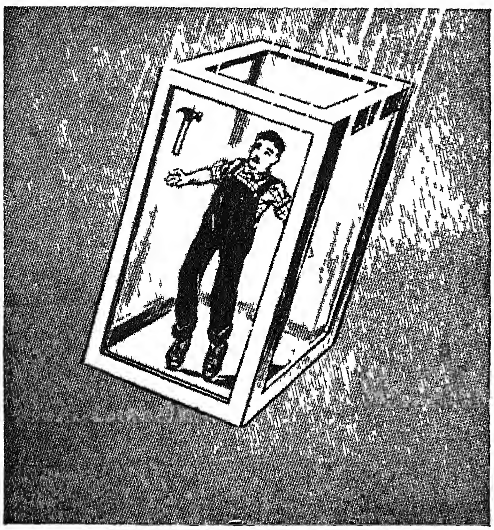
General Relativity

In the Special Theory of Relativity only a very special kind of change of the frame of reference was contemplated; the relative motion of the frames under comparison was required to be one of uniform translation. A much more general form of Relativity would be secured if any frame at all could be employed, or, still more generally, if we could use any kind of coordinates whatever —a set of "coordinates" being any four variables so chosen that the location in space-time of every possible event is represented by a certain set of values of the variables.

It would seem that such a description of natural phenomena ought to be possible, for the adoption of one particular frame of reference or kind of coordinates introduces an arbitrary element into the description to which there is no corresponding feature in the natural situation For example, a baseball when thrown by a fielder first rises and then falls, pursuing a parabolic path, if, however, the baseball diamond could be mounted on a platform that was itself falling freely through the air, then relatively to the diamond the same ball would move in a straight line The laws of motion in their usual form are thus different according as the motion is described relatively to the earth or to the falling platform Nevertheless Einstein was able to show, in an extension called the "General" Theory of Relativity and published in 1916, how the laws of physics could be stated so that their form actually would be the same whatever kind of coordinates are employed. The method, which involves the use of mathematical quantities called tensors, will not be further described here, except for a simple example given below.

The contemplation of such cases as that of the falling platform just described led Einstein to a remarkable novel view of gravitation, which he incorporated into his new theory. It might be said that relatively to such a freely falling platform there is no gravity at all, since a thrown ball travels in a straight line; scientists working on the platform could never tell by mechanical experiments whether they were

falling or not, for all of their results could be explained equally well either on the assumption that they were falling in a gravitational field or on the assumption that the platform was at rest and that no gravitational field was present. Such considerations suggest that what we call gravitational acceleration and force may in reality be fictitious phenomena due to an injudicious choice of reference frame, of the same nature as, for instance, the apparent force that presses us down upon the floor of an elevator when it begins to ascend. Einstein proposed therefore the "Equivalence Hypothesis", which reads as follows: "for any chosen point in space-time, a certain frame of reference can be selected such that, relatively to that frame and in the neighborhood of the chosen point, there is no gravitational acceleration and no other effect of gravity whatever. (More exactly, there exists for each point a class of such frames in uniform motion relative to each other") The novelty in this principle lies in its extension to phenomena that are not strictly mechanical; it implies, among other things, that light must "fall" in a gravitational field somewhat as does a material particle, so that the scientists on our platform, for instance, could not tell even by means of optical experiments (confined to the platform) whether they were or were not falling relatively to the earth.



To the man falling freely in a box in space it seems that nothing has any weight, for him gravity does not exist The earth, if he can see it, will probably seem to be falling toward him

The motion of the box is being slowed up by an invisible resistance It seems to the man that gravity has begun to act very strongly and he will immediately realize that he has been falling

If this view is correct, then the true law of gravitation must be a law stating a relationship between the different locally gravitationless reference frames, and it must be this relationship which is affected by the presence of gravitating matter. For instance, two frames of which one is gravitationless in New York while the other is gravitationless in Australia cannot be moving in the same way, and the reason lies in the presence of the earth between those two locations, either frame as viewed from the other must have an acceleration toward the other of 64 ft /sec.[2] Now for theoretical purposes it is convenient to take as the fundamental thing that is measured by means of a frame of reference, not distances and times separately, but what is called the "interval" between any two events, which is a sort of measure of their degree of separation in space-time. In a local gravitationless frame the interval between two neighboring events whose Cartesian space coordinates x, y and z differ by small amounts dx, dy and dz respectively and whose times differ by a small amount dt is defined as $ds = \sqrt{c^2dt^2 - dx^2 - dy^2 - dz^2}$ where c is the speed of light; as special cases, if the two events happen at the same time

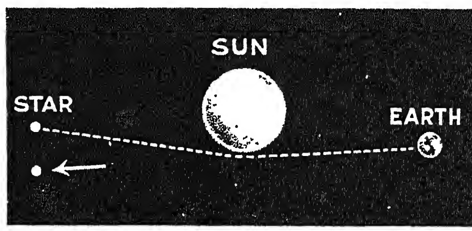
(as referred to this frame) dt is zero and ds is merely the ordinary spatial distance between the two points multiplied by $\sqrt{-1}$, whereas if they happen at the same place (as referred to this frame) ds is their difference in time multiplied by c. If we now introduce instead of x, y, z, t any new set of coördinates, x_1, x_2, x_3, x_4, in terms of which the location in space-time of each event can be specified, then ds takes the general form due to Riemann: $ds^2 = \Sigma(ij)\ g_{ij}\ dx_i\ dx_j$, where the summation is to extend over all values of i and j from 1 to 4 and the g_{ij} are functions of the coördinates whose forms will depend in part upon natural conditions and in part upon the choice of coördinates. The sixteen quantities denoted by g_{ij} are the components of a "tensor of the second rank", and it is their values which determine all gravitational effects.

The new law of gravitation must then consist of differential equations for the g_{ij}; and it must reduce very approximately under most circumstances to the well-known Newtonian law. In considering the various possibilities Einstein found one that was very much simpler than all the rest. Accordingly he adopted this simplest form as a tentative hypothesis, and proceeded to draw conclusions from it for observational test. Three such conclusions were found to involve effects large enough to be within the reach of present-day observation.

(1) The rates of occurrence of natural processes at different distances from gravitating masses ought to differ, comparison being made by means of signals transmitted to a single observation-post. For instance, atoms on the sun ought, when viewed from the earth, to appear to vibrate about a millionth part more slowly than do atoms of the same chemical element on the earth and the corresponding lines in the solar spectrum should in consequence appear very slightly displaced toward the red. The effect is confused by shifts due to other causes, but the result of prolonged study of the solar spectrum appears to be favorable to the Einstein theory. Much larger shifts ascribed to the same cause are observed in the light from one of the stars, the telescopic "companion" of Sirius.

(2) Light rays passing close to heavy masses should be deflected slightly toward them as if attracted (but twice as much as would follow from the Newtonian acceleration). The deflection due to the sun should be 1.75 a/r seconds of arc (a = sun's radius, r = distance of closest approach of ray to sun's center). This effect has been looked for by photographing stars seen near the sun during total eclipses and the results, although subject to considerable variation, appear to confirm the theory, the stars appearing displaced slightly outward from the sun and on the average by about the calculated amount.

(3) Planetary motions should be slightly altered, the chief effect being a progressive advance of perihelion about the sun which in the case of the planet Mercury should amount to 43 seconds of arc per century.



Light from a star on its way to the earth being bent as it passes by the sun. The arrow indicates where we on earth *think* the star is, on a straight continuing line with that part of the ray which is between the sun and the earth.

Now the perihelion of mercury is observed to advance 574″ a century, but 532″ of this is accounted for as due to perturbations by the other planets; for the residue of 42″ no explanation has ever been discovered by astronomers. This residue agrees with the additional effect predicted on the new theory.

On the whole the evidence seems fairly strong in favor of Einstein's theory of gravitation. Yet it must be remembered that the theory has as yet been tested only at a few points; it may in its turn some day require correction or further development.

The Extent of Space

Since the time of Newton space has generally been assumed to be infinite in extent, so that a physical body or a ray of light might move off along a straight line at constant speed forever without returning

to its starting point. This view being open to objections of a general sort, several slight modifications of the theory of General Relativity have been proposed which would make space finite in extent. According to the earliest of these hypotheses, due to Einstein himself, space is finite in much the same way as the surface of the earth is finite; two bodies can increase their distance apart only up to a certain enormous maximum, and a ray of light or a projectile, if not deflected by other matter, would eventually return to its starting-point, just as would a ship if it could be sailed over the ocean always straight ahead, i.e. along a great circle. Such a behavior of moving matter and of light rays might be due to an actual curvature of three-dimensional space into a fourth dimension, analogous to the curvature of the earth's surface, and for this reason the term "curvature of space" is often employed; but the assumption of such a fourth dimension is unnecessary and is not supported by any other evidence.

No evidence exists either for or against this speculation of Einstein's, but, curiously enough, there does exist some evidence in favor of a still more extraordinary hypothesis due to de Sitter. In this theory space is finite but light can never return within any finite time because of a lack of correspondence between the time scales in different parts of the world. It follows as an incidental consequence of the theory that material bodies, separated by great distances, will slowly scatter out as if under mutual repulsion. Now it is a striking fact that almost all of the spiral nebulæ which are believed to be very distant indeed, are moving at high speed away from us. On the other hand, two of these nebulæ are approaching rapidly, and for this reason the validity of de Sitter's theory must remain in doubt.

Writing on relativity, in the GROLIER ENCYCLOPEDIA for 1947, Einstein said, "The general theory of relativity is a generalization of the special theory of relativity, which removes the distinction of inertial systems as compared with co-ordinate systems of a different state of motion. This theory has its origin in a fact known for centuries that the inertia and the weight of a body are characterized by the same number (mass). It is in connection with this relation to weight that the theory has yielded a new law of gravitation, which is valid to a greater degree of accuracy than Newton's theory of gravitation.

"The following question is characteristic for the entire theory of relativity: How must the laws of nature be constituted so that they are valid in the same form relative to arbitrary systems of co-ordinates (postulate of the invariance of the laws of nature relative to an arbitrary transformation of space and time)?"

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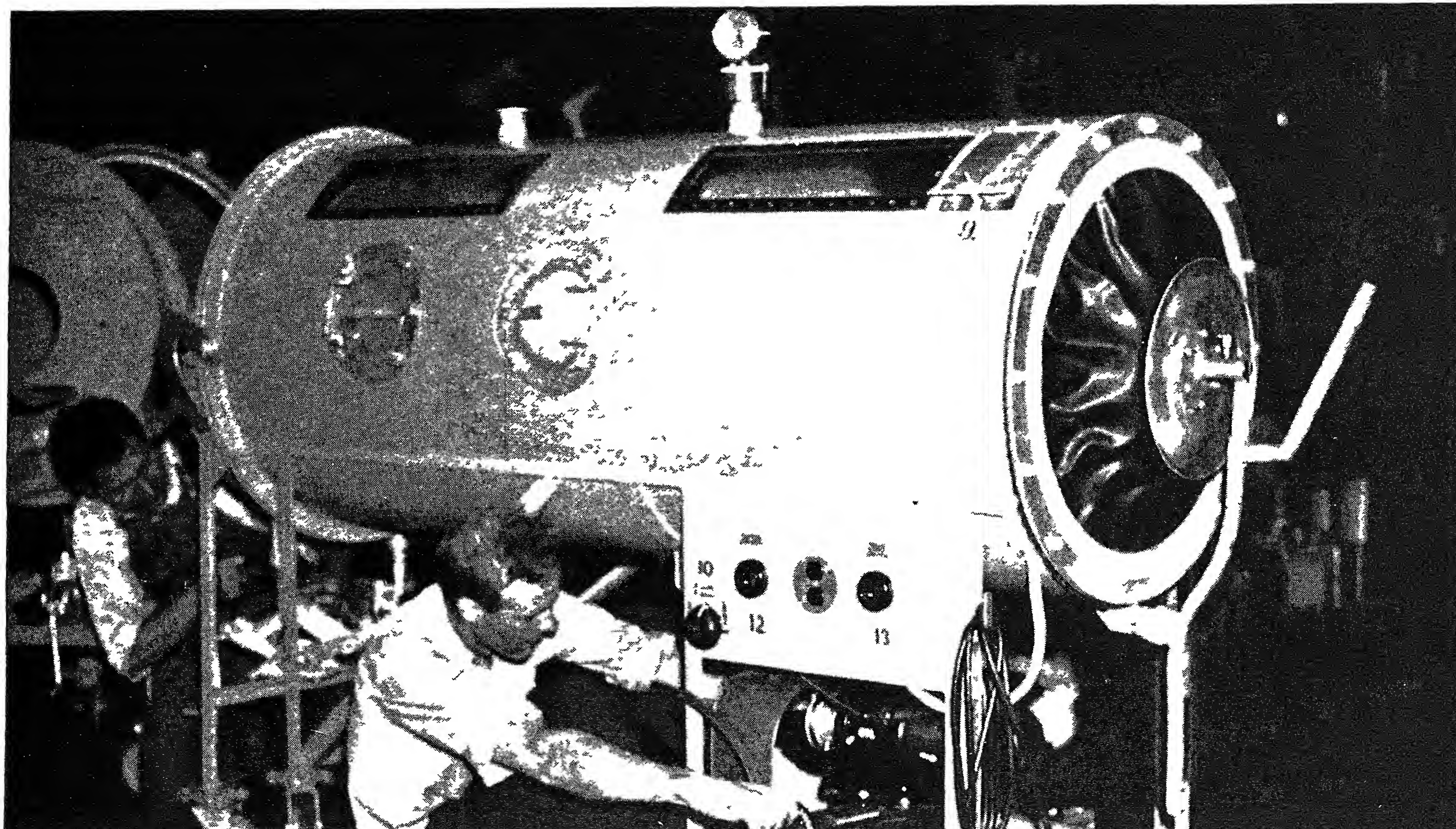
A VALUABLE ALLY IN THE WAR ON INFANTILE PARALYSIS



Wide World Photos, Inc.

J. H. Emerson, one of the two manufacturers of the "Iron Lung" (foreground) and an assistant put the final touches on one of their respirators. Known as the Emerson Diaphragm Respirator, the "Iron Lung" is designed to provide continuous artificial respiration over extensive periods of time for patients whose breathing mechanisms are temporarily inadequate or inactive. At present they are most widely known for their use by infantile paralysis victims, but they can also be used in gas poisoning, drowning, diphtheria paralysis and for the resuscitation of new born babies

RECENT PROGRESS IN MEDICINE AND SURGERY

by

WARREN T. VAUGHAN

Editor-in-Chief, Journal of Laboratory and Clinical Medicine

WITHIN THE PAST CENTURY the average life span of man has been greatly extended. The three factors which have wrought this change are advanced physical comfort, medicine and its handmaid hygiene and surgery. In the mitigation of actual pain, of physical torment which has racked every age down to the present, and which had scarcely even been alleviated till the past century, medicine stands incomparably first.

Little of importance in surgery except for rather crude treatment of wounds was achieved prior to the beginning of the 19th century. Before then most operations were performed upon accessible portions of the body, especially the extremities and usually in association with the wounds of war. Soon after 1800 daring surgeons ventured to enter the abdomen, operating for the most part upon ovarian tumors. The resulting deaths were staggering, but an increasing number of successful operations were reported.

The year 1846 is of utmost importance to the surgeon for it was then that general anesthesia was introduced. This made it possible to perform operations of election as well as those of necessity. Even so, infection of the surgical wounds was the rule rather than the exception and the death rate continued extremely high.

The next outstanding advance came in 1866, when Lord Lister, one of the few men of the day to accept Pasteur's theory of germs, applied the new concept to surgical practice, thereby inaugurating the era of antiseptic surgery. This is not surgery as we know it today, the modern aseptic surgery. The antiseptic surgeon operated in a carbolic acid spray, calculated to destroy all the germs with which it came in contact. Many were the cases of consequent carbolic acid poisoning. Nevertheless this was the beginning of modern surgery, which gradually evolved with the dawning realization that disease germs do not normally float about in the air except as they are introduced into the air from dirt or from the hands and mouth of man. Today, instead of attempting to destroy germs in the air with a spray, the modern surgeon prevents their advent into the air by perfect cleanliness, cleanliness of the operating room, the use of sterile linen and instruments, sterile gloves and a sterile mask.

Nowadays infection as a result of an operation is rare.

Since 1900 surgical practice has made tremendous strides, due not only to improvement in technical methods, but also to the fact that the surgeon has been able to utilize and to apply to his own needs discoveries that have been made in the other branches of medicine, in physics and in chemistry.

The old exploratory operation is almost a thing of the past, thanks to the advent of the X-ray which has enabled the surgeon to know what he will find before entering the tissues of the body. The X-ray has also been of aid to the surgeon in treatment. He finds radium most useful. Electricity in the form of the cautery or otherwise is used routinely by surgeons in the prevention of hemorrhage and in the control of local infection and to prevent the migration of malignant tumors.

With the aid of men in the other sciences he has evolved diagnostic instruments which would have been considered impossible a quarter of a century ago. With them he may look into the bladder, down into the bronchial tubes in the lungs and even down directly into the stomach, all of this prior to the operation. He may then operate with greater skill based upon more intimate knowledge, or not infrequently he may apply treatment with the same instruments, thus avoiding operation entirely. New instruments, today unheard of, will be in constant process of development just as today anesthetics and precision implements are being developed and employed which were unheard of even ten years ago.

Minor improvements, which one is apt to overlook, are really of utmost importance in facilitating better work on the part of the surgeon. These include improved hospitalization, improved nursing care, closer co-operation between surgeon and physician, and even such apparently insignificant factors as improved lighting of operating rooms, better instruments and operating room equipment.

Fifty years ago the surgeon's one interest was the removal of mechanical defects or impediments, such as an infected appendix or gall bladder, obstructed bowels, abscesses, cancers and the like. Today his interest is far broader in that he also directs his efforts toward a reconstruction of normal physiologic responses in tissues which although apparently organically sound are functionally abnormal. This has carried him into the realm of correcting abnormalities in the secretions of the ductless glands and in the activities of the nervous system. With threatening gangrene of the foot, the surgeon must no longer await the inevitable but may operate upon nerves remote from the site of trouble, thereby relieving pain and improving the blood supply to the extremity, sometimes thereby preventing the gangrene and amputation which otherwise were sure to occur.

Progress in surgery continues and will do so in the future as in the past, along paths that are undreamed of today.

Insulin—a major discovery

Replacing as it does a secretion which is no longer being manufactured in the diabetic, insulin enables the diabetic to live in comfort long past what would otherwise be his life expectancy. He must pay a price, for insulin must be given hypodermically. It is of no value when taken by mouth. Since one injection of insulin exerts its beneficial effect only for a matter of hours, the mild diabetic must give himself hypodermics once or twice daily, the severe diabetic three or four times daily. Up to the present no other drug has been found which may be taken by mouth with the same good effect.

But in 1936, a discovery was reported by a Danish physician, Hagedorn, which carried with it the promise of added ease for the diabetic.

Dr. Hagedorn has succeeded in combining insulin with a chemical substance known as protamine which precipitates the insulin, rendering it relatively insoluble. When this is injected under the skin it is slowly dissolved and as a consequence slowly liberated into the blood stream. As a consequence its effect is more lasting than that of insulin which sweeps rapidly into the blood and is as rapidly used up. Using protamine insulin or alternating doses of ordinary insulin and protamine insulin, the mild diabetic may now reduce his daily injections from two to one, the severe diabetic from three or four to two.

Protamine is a compound containing zinc. Recent investigations suggest that zinc alone will work as well as protamine.

Vitamin B and alcoholic neuritis

Alcoholic neuritis is an extremely painful disease which often afflicts habitual alcoholics, causing steady excruci-

ating pain in one nerve or another, most often in the nerves of the extremities. It has long been believed that this condition was due to the poisonous action of alcohol on the nerves.

The original discovery of the importance of Vitamin B as a constituent of foods was based upon the study of a form of neuritis known as beri-beri occurring among Japanese sailors. It was shown that beri-beri was due to a deficiency in the diet. The main article of food for these men was polished rice. Investigators demonstrated that the addition of the polishings from rice, the germ layer of the grain, to the polished rice cured beri-beri. There was some substance in the whole grain which was removed in the process of polishing which was necessary for the prevention of beri-beri. This was found to be Vitamin B.

Vitamin B is found in many foods but is especially abundant in the germ layers of the cereal grains. It is therefore more abundant in whole wheat bread than in white bread and is especially abundant in bran. It also occurs in large quantities in yeast which is used medically in the treatment of Vitamin B deficiency and is also found in liver. It occurs in many other foods.

Vitamin B has been isolated in the laboratory and obtained in pure crystalline form. It may be given in this form in the treatment of Vitamin B deficiency, even being administered intravenously.

It has long been known that habitual drunkards eventually develop such severe gastritis they are unable to eat normal quantities of food. As a consequence they consume more alcohol which they feel is the only substance which their stomachs will tolerate. Obviously a dietary deficiency is very likely to occur.

A few years ago the suggestion was made that in view of this and in view of the great similarity between alcoholic neuritis and beri-beri, the former may be due not to alcohol but to a Vitamin B deficiency, resulting from the inadequate diet. Within the last year or two a number of investigators have demonstrated that this is definitely the case.

First it was shown that these habitual alcoholics do have a Vitamin B deficiency in their diets. Next they were allowed to continue with the same alcoholic intake but were given adequate amounts of Vitamin B, either in their diet or in the form of crystalline Vitamin B intravenously. Their neuritis became cured. Further it was shown that chronic alcoholics whose customary diet had contained sufficient Vitamin B, did not develop alcoholic neuritis, in spite of continued alcohol intake.

The discovery that alcoholic neuritis is due to a Vitamin B deficiency provides a new method of treating this distressing disease.

Infantile paralysis or poliomyelitis

During the last few years much thought has been given to the disease known as poliomyelitis. Three years ago great hopes were raised in the discovery by two excellent investigators of vaccines which they believed would protect against the disease. An opportunity to test their effectiveness soon arose in the epidemic of infantile paralysis in the Carolinas, Virginia, Northern Ohio and to a lesser extent elsewhere. Altogether over 20,000 persons received the vaccines, one variety or the other. When follow-up studies by disinterested medical observers were completed the conclusion was reached that neither vaccine had demonstrated its effectiveness. Moreover nine cases of infantile paralysis were directly attributable to one of the vaccines. Seven cases occurred after the use of the other vaccine but were not as definitely due to the vaccine. We must therefore reach the conclusion that these two vaccines cannot be used in the prevention of infantile paralysis at the present stage of the study.

However, a most recent observation leads us to anticipate that in the next epidemic there will be a new method of treatment which will be tried very widely, and the effectiveness of which

will not be known until after the termination of the epidemic. It has been shown apparently conclusively that the virus of poliomyelitis enters the nervous tissues and the brain only through the nerves directly connecting the central nervous system with the nose. It has been shown experimentally in monkeys that these nerves can be effectively blocked against such migration of the virus from the nose into the nervous system by the local application of suitable dilutions of mercurochrome, tannic acid or picric acid, to the mucous membrane of the nose. We may therefore anticipate that with the next epidemic there will be a simultaneous widespread epidemic of spraying the nose several times daily, with one or the other of these substances.

Helium in medicine

We are accustomed to think of helium as an inert gas, nearly as light as hydrogen, extremely expensive, and used in lighter-than-air craft, chiefly because it is non-inflammable or non-explosive. It is rather difficult to imagine offhand how this gas could be of use in medicine.

However, Dr. A. L. Barach has devised a very clever and at the same time very important function for helium in the treatment of disease. It may be used in asthma and in other diseases which obstruct the passage of air through the air tubes in the lungs. Helium is seven times lighter than nitrogen. Nitrogen constitutes nearly four-fifths of the air that we breathe. Oxygen accounts for approximately 20 per cent. Therefore persons who experience difficulty in getting air in and out of their lungs may breathe a mixture of 20 per cent oxygen and 80 per cent helium, finding the process seven times easier than that of breathing ordinary air.

Owing to the high cost of helium this has not come into general use but is employed in the severest cases of asthma and in obstruction to the air passages from other causes, such as pressure from a tumor, obstruction with foreign bodies and the like. Since the United States Government controls the helium production in this country there is a probability that the Government will make medicinal helium available at a cost to the patient no greater than that of medicinal oxygen.

Allergy to cold

From the earliest times it has been recognized that certain individuals react in an unusual manner when brought into contact with extraneous substances. Probably the most typical and earliest recognized of these manifestations was the condition known as food idiosyncrasy. In 1906 von Pirquet introduced into medicine the term "Allergy" to indicate this state of altered reactivity on the part of man and animals to certain foods and other substances. Lately it has been learned that not only may one have idiosyncrasies to certain foods or drugs, or sensitization to substances which are inhaled such as pollen, dust, feather dust and the like, but one may also be hypersensitive to physical agents such as heat, cold and sunlight or the actinic rays (ultraviolet). The commonest sensitization to these physical agents is that to cold. The three commonest manifestations of such sensitization are urticaria or hives (nettle rash), asthma and fainting or collapse. These symptoms may occur following exposure to only moderate cold or, in less sensitive cases, after exposure only to severe cold. Under any circumstance the disease is not common. Less than a hundred cases have been described in the medical literature, but there are undoubtedly thousands that have never been described in writing and possibly have never been recognized.

The first written description of such a case was made by a Frenchman in 1867. Occasional cases were mentioned in the medical literature until 1924 when Dr. W. W. Duke described a number of cases and gave it its present name of "physical allergy."

In 1936 Doctors Horton, Brown and

Roth described 22 cases which they had seen and studied most carefully. They collected from the literature records of 76 persons who reacted allergically to cold. Twenty-nine of them reacted so severely as to have severe general reactions and 18 experienced fainting from exposure to cold.

The point of greatest interest in these cases is that 15 of the 76 had had the experience of fainting following swimming in cold water. Eight of them had fainted while in the water and had had to be rescued. It seems probable, although difficult of proof, that many, possibly the majority of cases of drowning in persons who are able to swim, drowning that is usually described as due to cramps, is actually due to allergy to cold.

Allergy to dental plates

It appears that one may be allergic or hypersensitive to almost anything with which one comes into contact in his environment. There are undoubtedly millions of persons in the United States wearing dental plates. Most wear them without inconvenience or only a mechanical inconvenience.

Within the last year or more various substitutes for the familiar vulcanite have been developed, which make equally effective dental plates but which are derived from chemical compounds not previously used extensively in artificial dentures. During 1936 one doctor in Chicago described three cases of severe irritation of the mucous membrane of the mouth due to the use of these newer synthetic plates. These persons were definitely allergic to the material as was demonstrated by the fact that when the plates were attached to the skin of the arm by adhesive and left in contact for 24 hours, an eczema appeared at the site of contact. The removal of the plate from the mouth cured the disease. One may be allergic even to one's dental plates.

Virus diseases

The word virus means poison. In the early days of the study of infectious diseases the term came to be used for any germ that caused an infection. However, the name has become very much more restricted medically and is usually employed to indicate a living germ, so small that it cannot be seen with the microscope, and usually one that has not yet been identified. Formerly we spoke of the virus of typhoid fever. But the typhoid bacillus has been identified as being one of the bacteria and is no longer termed a virus. Today infectious diseases are recognized as being due to one of the following disease agents: bacteria, spirochætes, fungi, protozoa, Rickettsia and viruses. Today the term virus does not include all infectious diseases of unknown causation. In addition to the above list there are infectious diseases of unknown origin. The virus diseases are now very definite diseases. They include the following: measles, German measles, mumps, fever blisters, herpes zoster (shingles), chicken pox, smallpox, smallpox vaccination or vaccinia, rabies or hydrophobia, psittacosis or parrot fever, the common cold, influenza, encephalitis, poliomyelitis, foot and mouth disease, yellow fever, dengue fever, warts and a few more that are quite uncommon.

A virus is quite different from a bacterium. The latter can live and reproduce its kind in an artificial culture medium such as a tube of beef broth. It may be seen and studied under the microscope. A virus on the other hand is so small that it cannot be seen under the microscope, is indeed but little if at all larger than a chemical protein molecule. It must live inside of a living cell. In the human or animal body, once it has gained entrance it actually enters living cells where it grows and produces disease. It is because of the protection which the living cell affords it that serums are of no value in the treatment of virus diseases.

Viruses cannot grow outside of living cells. Furthermore these must be cells which are susceptible to invasion by the virus. For this reason the only way in

which they may be studied in the laboratory is by keeping them alive through growth in laboratory animals. There is one exception in that one virus, that of cowpox, will grow in chicken-embryo tissue.

The virus of yellow fever may be mixed with immune serum and used as an effective vaccine against the disease. This is different from the use of serums for the treatment of disease, once it has occurred.

Evidence is gradually accumulating that the human body serves as host to myriads of viruses, most of which are quite harmless, just as it does to the bacteria that infest the skin, mouth and nose and the intestinal tract. There is, however, this difference, that while bacteria live in the nooks and crannies, viruses live inside the living tissue cells themselves. Normally, bacteria not only live in the intestinal tract but actually enter the structures of the body, even the blood stream, without causing damage. They are removed chiefly by the liver and by other tissues and cells that exist for this purpose. There was a time when it was believed that if any bacterium actually penetrated the body, either from the skin or from the intestinal tract, disease would result. Today we know that this occurs continuously and that disease results only when certain types of bacteria enter, or when the body resistance is lowered.

The antibiotics have revolutionized the treatment of disease

Scientists have quite recently developed a number of new bacteria-killing drugs called antibiotics. They are made from substances that are produced by living organisms, such as fungi or bacteria. Therein they differ from the sulfa drugs, which are derived from coal, air, water and other inorganic substances.

The first of the antibiotics to attract wide attention was penicillin, an acid produced by the mold *Penicillium notatum.* An English scientist, Sir Alexander Fleming, discovered in 1928 that his cultures of bacteria would not grow in the presence of this mold. About ten years later a group of other scientists found that the bacteria-killing agent was penicillin, which is secreted by the mold. At first penicillin was expensive and scarce, but improvements in manufacturing methods have now made it available to the public at large. It is used extensively to combat infections of the blood, heart, eyes, ears and bones. It also helps to prevent infection in open wounds; it was widely used in the second World War for that purpose.

Streptomycin rivals penicillin as a germ-killer; it is an extract of *Streptomyces griseus,* a bacterium that grows in the soil. Streptomycin was discovered in 1939 by Dr. Selman A. Waksman and others at Rutgers University. Streptomycin is effective against certain types of bacteria that resist penicillin and the sulfa drugs; it is particularly useful in treating pneumonia, typhoid fever and gas gangrene.

Aureomycin, which comes from a gold-colored mold, has been used successfully in the treatment of various virus-caused diseases, such as virus pneumonia, Rocky Mountain spotted fever, undulant fever and typhus. Terramycin, another earth-mold derivative, is effective in treating pneumonia, blood-poisoning, tonsilitis and septic sore throat. Other promising antibiotics are Chloromycetin and Viomycin.

Two hormones that provide relief for sufferers from arthritis

The hormones known as cortisone and ACTH (an abbreviation for adrenocorticotrophic hormone) have proved amazingly effective in the treatment of arthritis. Cortisone is made chiefly from the bile of cattle, and ACTH, from the brains of hogs; but there are other sources. The two hormones do not cure arthritis but they provide effective relief for sufferers. They have also been used experimentally in treating hay fever, asthma, hardening of the arteries and other ailments. Unfortunately cortisone and ACTH are still very expensive and scarce; besides, they sometimes have unfortunate aftereffects. They may bring on nervous disorders, increased blood pressure, or hairy growths on women's faces; they have sometimes caused water to collect in the tissues of the body.

THE CLEANING OF FABRICS

"Saw how, by sorrow tried and proved,
The blackening stains had been removed."

THE REMOVAL OF STAINS AND BLEACHING

THE life and beauty of any fabric can be very much affected by the methods used in the cleaning processes. Probably most danger lies in the indiscriminate use of chemicals to remove stains or to whiten clothes. Some bad effects are also doubtless caused by incorrect methods of laundering, often with unsuitable materials, and reference will be made to this in another chapter.

Any coloring matter deposited on a fabric other than that intended as a dye may be regarded as a stain, and any process used to remove such stain may be called a bleaching process, and the reagent used is the bleaching agent. If people would realize that stains are removed most easily when fresh, and very often then by the use of water alone, there would be little necessity to use any stronger reagent. Unfortunately, stains are allowed to dry in, and their removal is more difficult, but can usually be effected by means of various chemicals, the use of which is comparatively safe provided certain rules are followed.

The business of stain removal is facilitated if we know (1) the nature of the stain, (2) the nature of the fabric, and (3) the action of the reagent to be used on the fabric. If we know what the stain is, it is best to use the method which has proved successful and harmless by long experience: such, for instance, as the removal of ink from cotton and linen by the use of oxalic acid. If the stain is an unknown one, try the simpler methods first, and resort to the use of stronger measures only it absolutely necessary.

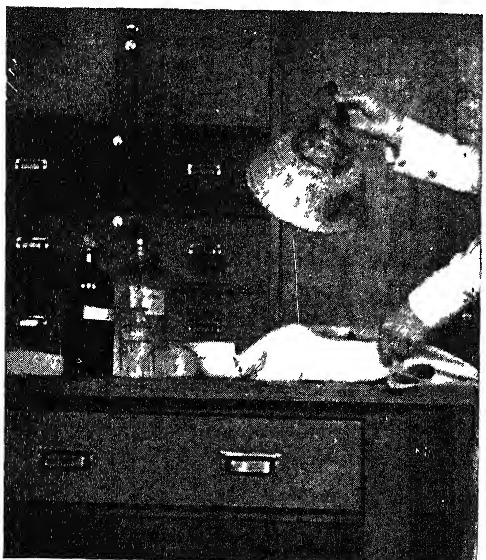
Stains should also be removed at once to avoid permanent injury to the fabric. Some acids will not only affect the color of the fabric, but will, if allowed to dry in, actually destroy the material as they concentrate on the fibers. Strong acids will destroy the fabric in a few seconds. Lye will not only affect the color of wool but will also dissolve the wool, if in contact any length of time. To avoid such destruction and effect on the color by acids and alkalies, treat with water immediately, and then neutralize an acid by applying an alkali such as dilute washing soda solution or ammonia; and neutralize an alkali by applying vinegar. In both cases a harmless soluble salt will be formed which can be removed by thorough rinsing.

The stain should always be attacked before the material is washed with soap and water, as this may tend, in some cases, to fix the coloring matter on the fabric; and if the material is starched, the starch must be removed by water before chemicals are used, as its presence may delay the action of the latter.

Always begin with cold water. Sponge the fabric, or soak it, or even allow the cold water to run through the fabric from a height of about twelve to eighteen inches if the material will permit this treatment. Cold water will remove many stains if sufficient time is allowed. Certain stains — those, for example, like blood, meat juice and egg, which contain protein substances — coagulate and harden with heat; therefore hot water in these cases should be avoided until the stain has been removed by treatment with cold water.

What to do if cold water is ineffective

If, however, cold water is found to be ineffective, use warm water or warm water with a very little borax or ammonia dissolved in it. This will remove many freshly made fruit, tea and coffee stains. A delicate material may be sponged gently. Hot water poured from a height of about twelve to eighteen inches through the fabric stretched over a basin is often very effective in cases of cooked fruit stains.



Pouring hot water from a height of 12–18 inches through a stained fabric

Many stains can be removed by a prolonged exposure to light and air, and this method causes the least possible deterioration in the fabric. It consists in spreading the wet fabric on the grass or on a towel in the sun, and as it dries, remoistening with water. Several days' exposure may be necessary, but will usually remove many obstinate stains as well as the yellow tinge which clothes acquire with incorrect washing methods or on storage. The whiteness of clothes which are habitually dried in the sun and air is due to this mild bleaching process. The process is one of slow oxidation, but owing to the time required, and the impracticability in towns, it is often necessary to resort to more rapid methods of bleaching where simple treatment fails.

The bleaching agents and stain removers which can be used conveniently in the home laundry are:

(1) A solution of bleaching powder or chlorinated lime known as "bleaching liquor"; or the solution of the corresponding sodium compound known as "Javelle water."

(2) Hydrogen peroxide.

(3) Oxalic acid or the corresponding potassium compound known as "salts of lemon."

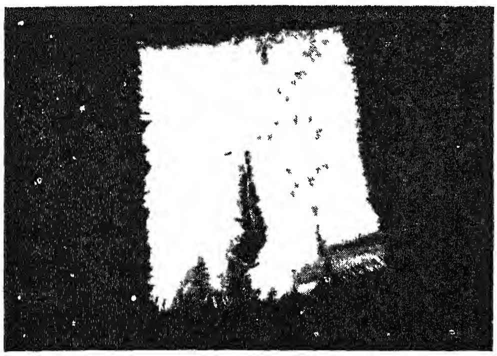
(4) Benzine, benzol, gasoline, methylated spirits and turpentine, for grease, paint, tar, etc.

The use of bleaching powder or chlorinated lime

Bleaching powder is made by passing chlorine gas over slaked lime (calcium hydroxide). The active agent in the resulting compound is the chlorine after it is set at liberty again. It is then known as "available chlorine." A fair sample of freshly prepared bleaching powder contains about 30 to 35 per cent available chlorine, but on keeping, or on exposure to the air and moisture, it tends to decompose and lose some part of this. It is entirely unsuitable to use on silk or wool, the fibers of which are rendered harsh and brittle even by dilute solutions. Its use is restricted to the bleaching of linen and cotton (cellulose materials), and even these may be affected by carelessness — linen more easily than cotton.

Bleaching liquor of the greatest strength which experience shows is safe to use is prepared by mixing one ounce of the powder to a creamy consistency with a little water, then diluting to one gallon with warm water. This should be well stirred and when solution is complete, allowed to settle. This solution of calcium hypochlorite ($CaOCl_2$) will contain about 0.2 per cent available chlorine. The clear liquid only should be used. If the fabric is immersed in the turbid liquid, there will be overbleaching with the formation of oxy-cellulose where the solid matter comes in contact with the fabric; and tendering, or even destruction, of the fibers at these places will follow.

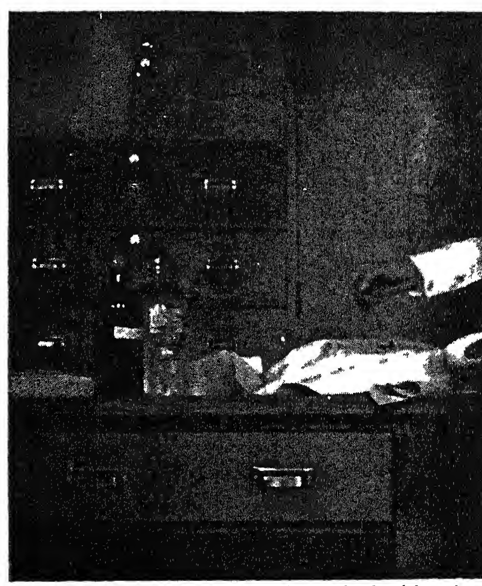
Unfortunately this calcium compound tends to form a sticky, insoluble calcium soap, or curd, on the fabric during the subsequent washing process with soap and water. To avoid this. the preparation can be converted into the sodium compound sodium hypochlorite ($NaOCl$) by



A piece of cotton material which has been destroyed by careless use of bleaching liquor

the addition of washing soda. The product is then known as "Javelle water," and the quantities to use are one ounce of bleaching powder and four ounces of washing soda to one gallon of water; or, more conveniently, use one quart of water instead of one gallon, and, after allowing it to settle, any quantity of the clear liquid can be diluted at the moment of using with three times its volume of water to make it of the same strength as that described. Hot water may be used for diluting. Whichever preparation is used, the stained portion of the fabric should be steeped for *a few minutes only* in the clear liquid. A certain amount of bleaching will take place in this solution, but the action is more rapid, with consequently less destruction of the fabric, if the material is transferred without rinsing to a bath of dilute acetic acid (of about 2 to 3 per cent strength) and left for a few seconds. Vinegar diluted with an equal volume of water is convenient. If after rinsing in clear water the stain is not completely removed by the one treatment, repeat several times with thorough rinsing between each treatment. A dropper or glass rod can also be used to apply the reagents to the fabric stretched over a bowl containing water, and the fabric can be rinsed in this water very easily before a second application is made. Prolonged steeping in either bleaching solution is to be avoided, and several short treatments in a warm (not hot) solution are more effective and less detrimental than one extremely long treatment in a cold solution would be.

When the solution of either the calcium or the sodium compound is followed by acetic acid, hypochlorous acid ($HOCl$) is formed which in turn gives up its oxygen to the stain, thus converting it into a colorless compound and being itself reduced to hydrochloric acid (HCl). The hydrochloric acid again reacts with the sodium or calcium acetate which has been formed during the reaction, and acetic acid is produced and left on the fabric in a free state. Even if acetic acid is not thoroughly removed by the subsequent rinsing, it will have little, if any, bad effect



Applying a stain-remover with a glass rod, the fabric being stretched over a basin of water

on the fabric as it dries. Dilute hydrochloric acid can be used throughout the process in place of acetic acid, but a certain amount of free chlorine will be produced during the bleaching process and hydrochloric acid will be the end-product left in the fabric. If hydrochloric acid is not completelv removed by the rinsing

process or by neutralizing it with a little alkali, it will concentrate in the drying process and the fibers will be disintegrated more or less according to the amount left in. Acetic acid is therefore the safest acid to use with the bleaching solutions. In any case, the fabric should afterwards be washed thoroughly in soap and water and again rinsed and dried.

Bleaching liquor or Javelle water, followed by acetic acid, can be used for removing old tea, coffee, and fruit stains, some medicine stains, perspiration, and dye stains. It can also be used for bleaching cotton fabrics which have become yellow with age, the whole article being immersed in the fluid as described above. Bleaching solution will sometimes remove most of a stain, leaving a slight discoloration which will probably disappear in the subsequent washing process, especially if the fabric is boiled. This should be tried before a second bleaching method is attempted. Chemicals which will remove stains will very often remove the dye from a colored fabric and consequently must be tested out first on a sample of the material. Bleaching liquor and Javelle water cannot usually be employed with colored fabrics.

It is important to emphasize the point that the use of bleaching liquor or Javelle water should *never* be part of the ordinary washing process. The practice of adding "bleach" to the soapy water or to the boiler with the idea of improving the color of the goods is to be condemned. The destructive action on the fibers is increased with the prolonged treatment and with the higher temperature, and the oxy-cellulose so formed will again react with sodium carbonate in the next wash, even when present in only small quantities, to form a yellow-colored substance. Consequently fabrics so treated require bleaching every time if the yellow color is to be avoided after subsequent washings.

The use of hydrogen peroxide

Hydrogen peroxide (H_2O_2) is probably concerned in the natural process of bleaching by sunlight and by exposure of soaped articles on grass during dews and frosts. It bleaches by giving up part of its oxygen to the coloring matter of the stain and thus converting it into a colorless compound. The commercial preparation is usually sold in the form of an aqueous solution described as a "ten volume solution" or "twenty volume solution" according to its strength. The ten volume solution contains about 3 per cent real hydrogen peroxide, and for bleaching purposes must be diluted up to ten times its volume with water, making a 0.3 per cent solution. The solution, as purchased, has been rendered more stable by having had a trace of acid, usually sulphuric acid, added to it; and in order for the preparation to decompose easily for bleaching, and to prevent the destruction of fiber by the acid as it dries, this acidity must be neutralized by the addition of a few drops of ammonia. The solution should be made warm and the article to be bleached should be left in it about half an hour, then lifted out and dried slowly in air and light.

As a bleaching agent hydrogen peroxide is slow and several repetitions may be necessary, but it is suitable for use on wool and silk, as bleaching liquor cannot be used on these. It will frequently remove a fresh ink stain from white or light silk and wool, and is particularly useful for the removal of slight scorch from cotton or silk. The residual stain which is sometimes left when blood stains have been treated with cold water and afterwards washed, and the residual stain which is left after fruit stains have been only partially removed with water, are quite often successfully removed with hydrogen peroxide.

Oxalic acid and salts of lemon

Oxalic acid ($C_2H_2O_4$) is very useful for removing any stains containing iron compounds, such as iron rust or ink. "Iron mold" may be produced on a fabric by the presence of iron in the water and in parts of machinery with which the fabrics come in contact, and by the decomposition of a laundry blue containing iron compounds when it comes in contact with washing soda or soap — a property of Prussian blue which makes it unsuitable for laundry work.

Some black writing inks will also generally be found to contain some iron compounds, though they vary considerably in composition; and in addition they may have added coloring matter — usually a dark blue dye. Both iron mold and black writing ink stains containing iron can therefore be removed by treating them with a solution of oxalic acid which reacts with the iron compound and converts it into a soluble salt which can be rinsed away. With the ink, however, there is frequently left a green residual stain which is removed in the subsequent process of washing and boiling.

The oxalic acid crystals should be dissolved in water; a saturated solution, that is, a solution in which no more of the solid will dissolve, and which can be recognized by the fact that some undissolved solid material lies at the bottom of the vessel, can be prepared for a stock solution, and when required, any volume of it can be diluted with two or three times its volume of water and the stain can be treated with this for a few minutes or until it changes color, when it should be thoroughly rinsed. A warm solution can be used on cotton and linen, and short treatments repeated several times are much better than one long treatment.

Salts of lemon (or potassium acid oxalate) can be used in place of oxalic acid in exactly the same way. Salts of lemon, in cold, very dilute solution, can also be used on silk. But whichever is used, it is highly important that it be thoroughly rinsed out, the last rinsing water having in it a trace of an alkali such as ammonia to make sure that the acid is completely removed. If oxalic acid is allowed to dry on the material, it concentrates as it dries and rots the fabric.

Citric acid or lemon juice is often equally successful in removing iron stains, a soluble salt being formed which can be removed by rinsing. Soaking the fabric in milk, changing as often as it becomes discolored, is another successful method.

Oxalic acid and salts of lemon can also be used for the removal of old fruit and tea stains from cotton and linen. They are both very poisonous compounds.

Some special stains and how to treat them. Chocolate and cocoa

We may now consider some special stains and their treatment. Ordinary laundering with hot soapy water will generally remove those of chocolate and cocoa, which contain fat, coloring matter, fibrous material, starch sugar, and sometimes milk. Some of the staining material can often be removed with a dull knife. Soaking in borax and cold water, followed by a hot rinse, is good for washable material. Sponging with lukewarm water is substituted for the hot rinse on delicate fabrics. If a grease spot is left after this treatment, a grease solvent must be used.

Ice-cream stains contain milk or cream, sugar, sometimes egg, and frequently chocolate or fruit juice. If the stain from the fruit juice or chocolate is excessive, sponge with cold or warm water and apply the methods suggested for fruit stains, chocolate, etc. If a grease spot is left, use a grease solvent on a non-washable or soap and water if a washable fabric.

From washable material, grease marks are removed by ordinary laundering. On a non-washable material, a grease solvent must be used as explained below. The removal of machine grease, which usually is a mixture of grease and finely divided carbon, is best effected by rubbing in fresh grease, either lard or oleic acid, to soften the stain, and when it has thoroughly penetrated kneading and squeezing in dilute ammonia if oleic acid was used, or if lard rubbing in a soapy lather with a little ammonia added. As the soap is kneaded and pressed through the material, it carries the dirt loosened by the softening of the grease with it, and the whole can then be washed in fresh soapy solution with a trace of ammonia in it. If such grease marks are attacked with the ordinary laundry methods, the grease may be spread with the heat of the hot water and much of the dirt left behind in a patch.

Thorough, but gentle, rubbing with soap and water removes grass stains to some extent. As the coloring matter is soluble in methylated spirits, this can be applied to unwashable materials.

Iodine stains can be removed very easily, if on starched goods, by merely boiling in clean water. The iodine and starch together form "starch iodide" which is decomposed by heat. If the article is not already starched, boil the cotton or linen in water to which a little starch has been added. If the material is one that cannot be boiled, soak for a long time in cold water, or sponge with methylated spirits.

There are several laundry blues in common use and the removal of an excess of any one of the different kinds requires a different method; that of Prussian blue has been dealt with above. The laundry blue most commonly used is ultramarine, a solid compound which can be recognized by its sky-blue color. It is insoluble in water and its use depends on the fact that when the minute particles are deposited on the slightly yellowed fabric, the impression to the eye is one of whiteness. The clothes are not really being whitened at all but *appear* to be so. Ultramarine is decomposed by dilute acids, so that any excess on a fabric can be removed by soaking in warm water containing a little vinegar.

The liquid or soluble blues which are now frequently used are usually solutions of aniline compounds and are really dyes, and the removal of excess is difficult. Acids set the color on the fabric. Sometimes the dye is partially removed by soaking for a long time in cold water and by the washing process and particularly by the bleaching action of the sun in drying. But owing to the fact that the material is really dyed and that the color is difficult to remove, the use of this laundry blue is to be regretted.

Medicine stains vary so much that no rules can be given for their removal, and it will be necessary to try one reagent after another. If their nature is known, a suitable method is selected according to their composition and the nature of the fabric.

If mildew is attacked when it is very fresh, it will come out by boiling in the usual way. It is sometimes removed by bleaching in the sun, but this treatment may have to extend over several days. Sometimes it can be removed with Javelle water; but if it has been allowed to dry in the fibers, it is very difficult, indeed almost impossible, to remove.

Most of a paint stain can be removed immediately it is made by scraping it with a dull knife, and from a washable material the residue will frequently disappear with careful washing with plenty of soap. Older stains can sometimes be removed by first thoroughly rubbing in oil or lard and working this into the material until the stain is softened. It is then washed with soap and water. Sometimes boiling in water containing three tablespoons of washing soda to a gallon of water is effective, but many fabrics will not stand this treatment. On material which is not washable, one of the grease solvents discussed below must be used.

Red ink is usually a preparation of an aniline dye and is often very difficult to remove; in some cases, the strongest reagents will only be partially effective. It should be attacked immediately the stain is made, and then can sometimes be removed with ammonia or with a saturated solution of borax.

Scorch marks are produced by the overheating or overdrying of a fabric and are really due to the charring of the material. The removal of the scorch consists in removing the particles of carbon from the surface of the fabric either by the mechanical action of gently rubbing in soapy water, or by the use of an oxidizing agent such as hydrogen peroxide or Javelle water, both of which will convert the carbon into carbon dioxide. If the charring is excessive, so much of the fabric will have been carbonized that its removal will cause a hole to be made in the fabric.

The use of grease solvents, their danger and their proper application

Theoretically any liquid which dissolves grease can be used to remove grease spots, or to "dry-clean" fabrics. Usually the grease entangles a considerable amount of dirt and this is removed during the process of dissolving the grease.

The liquids commonly used are products obtained by the fractional distilla-

tion of crude petroleum or the paraffin oils and are benzine, light petroleum, and gasoline. They are highly inflammable liquids and should *never* be kept or used near any flame or open light, and the bottles containing such solvents should be clearly labeled "Inflammable." Commercial benzine or benzol (C_6H_6) is a product obtained from the distillation of coal tar, and is a very good solvent for grease, tar and paint. Carbon tetrachloride (CCl_4) may also be employed, but its anæsthetic properties make it open to objection for home use; it is a component of many commercial preparations sold for re noving grease.

None of these solvents should be applied directly to the spot at first, but the surrounding fabric should be saturated with it. The surface tension will then be greatest in the region of the grease and the grease will be forced towards the center of the mark, carrying the dirt particles with it, and the grease in solution can then be absorbed by blotting paper or other absorbent material placed under the fabric which is being cleaned, or with which it is being rubbed. If, on the other hand, the liquid is applied first to the grease mark, the grease, solvent and dirt will spread into the surrounding fabric, leaving a clean spot in the middle and forming a dark ring around. Spread the fabric, therefore, face downwards on a pad of clean blotting paper or rag and apply the solvent with a sponge or piece of fabric of the same color as the material itself, first to the fabric around the mark until it is well saturated, and then to the mark itself, working gradually towards the center, and rub gently till the solvent has evaporated, using a clean piece of material to rub with whenever the one in use becomes soiled.

The removal of solid fats and wax by absorption

Solid fats can sometimes be removed by the application of heat together with the use of an absorbent material. This method is also particularly good for the removal of such stains as the marks of paraffin wax which does not spread but hardens on the cloth. If the wax is melted by the application of a hot iron, it can be absorbed by any absorbent material such as unglazed brown paper or blotting paper placed above and below. If the wax is colored, the dye can then be removed by sponging it with methylated spirit, and if any trace of stain is still left, it can be removed with a suitable solvent.

Absorbent materials such as fuller's earth, French chalk, or white talcum powder can be applied to fine materials, and salt or corn meal to carpets and coarse materials, to remove liquid grease or oil which is unmixed with dirt. The powder should be laid over the stain and worked round gently. When it becomes sticky, shake or brush it off and repeat. The final application can be allowed to remain on the fabric for a number of hours. This is the same principle as is used when salt is laid on a fruit stain on a table cloth or on an ink stain on a carpet. The staining material is absorbed before it has time to penetrate the fabric to any extent or unite chemically with it.

Paint stains and varnishes on non-washable materials

Paint stains on materials which are not washable, or which have been allowed to harden and dry in the air, should be first softened by rubbing in turpentine, and then sponged with more turpentine. Carbon tetrachloride and benzol are also good solvents of paint. Turpentine and ammonia together, allowed to act for a length of time, will also be effective. But no method will remove very old stains which have been thoroughly oxidized in the air.

Turpentine, benzol, carbon tetrachloride, methylated spirits, gasoline or kerosene may be used for varnishes. Sponge the stain or rub it gently with the solvent. For tar stains, benzol is the most suitable agent. For vaseline stains, gasoline, turpentine or kerosene are useful.

In conclusion, whenever the staining material contains several ingredients, each ingredient may have to be treated according to its nature. And whenever the stain is being removed by chemical means the effect of the reagent on the fabric itself and on the color must also be kept in mind.

Metropolitan Museum of Art

The American Revolution became a full-scale revolt with the Battle of Bunker Hill (above). It inaugurated a period of political upheaval that had its counterpart in the fields of science and technology.

Science in Revolution (1765-1815) I

by JUSTUS SCHIFFERES

AN AGE OF REVOLUTION

THE last third of the eighteenth century was the period of the political upheavals that we know as the American and French revolutions. In this era there also occurred an Industrial Revolution and a Chemical Revolution, which were likewise supremely important. The Industrial Revolution involved the substitution of machinery for hand tools, the introduction of the factory system and the rise of mass production. In the course of the Chemical Revolution, old, erroneous theories were rapidly overthrown and the science of chemistry was placed on a firm foundation.

It has been pointed out that revolutions are simply signals that evolution has taken place. The forces that produce them have been gathering momentum for a long time before they break out into visible and sometimes violent changes of existing conditions. The American Revolution, which began in 1775, resulted from the gradually increasing strength of the colonies and their growing unwillingness to play a subordinate role, as well as from such specific happenings as the passing of the Stamp Act (1765), the Boston Massacre (1770) and the Boston Tea Party (1773). The age-old misery of the French peasants, popular displeasure over the privileges enjoyed by the upper classes and the spirit of defiance engendered by the French "philosophers" of the eighteenth century — all these factors had molded the spirit of the French people over a period of many years, so that the actual outbreak of revolution in 1789 came merely as a long-anticipated climax.

So it was with the Chemical and Industrial revolutions. The Chemical Revolution did not spring full-fledged from the brow of some scientific Zeus. It was the product of many generations of scientists and pseudo-scientists, who had gropingly accumulated facts and advanced theories. The Industrial Revolution, in its beginnings, was not so intimately bound up with the history of a science, but it was rooted partly, at least, in earlier scientific achievement. It waxed and grew as men realized more and more that the methods of scientific thinking could be applied to the problems of industry and could bring about astonishing improvements in the manufacture and distribution of goods. One of the important results, indeed, of the Industrial Revolution was the development of applied science, or technology.

The statesmen, political teachers and military men of the Age of Revolution were not unaware of the importance of scientific and technological developments. The leaders of the American Revolution included a number of men noted for their contributions to science; most famous among them was Benjamin Franklin, whose electrical experiments we shall discuss later And there were others. Dr. Benjamin Rush, like Franklin a signer of the Declaration of Independence, wrote on anthropology (the American Indian and his vices) and medicine (yellow fever, jail fever and military hygiene). Thomas Jefferson declared that "Nature intended me for the tranquil pursuit of sciences by rendering them my supreme delight." He was thoroughly familiar with the natural sciences and with higher mathematics When he rode into Philadelphia on horseback in 1797 to be inaugurated as vice-president of

The mass attack on the infamous prison known as the Bastille, in July 1789, was one of the truly memorable events of the French Revolution.

Culver Service

the United States, he carried in his saddlebags a collection of fossil bones and a manuscript describing them. He later read this manuscript to the members of the American Philosophical Society, of which he had just been elected president.

In the Constitution of the Commonwealth of Massachusetts, adopted in 1780, legislators and magistrates are urged to "cherish the interests of literature and the sciences" and to encourage societies and institutions for the promotion of sciences, common trade and the natural history of the country. The Constitution of the United States, officially adopted on March 4, 1789, states that Congress shall have power "to promote the progress of science and useful arts by securing for limited times to authors and inventors the exclusive rights to their respective writings and discoveries."

There was a time in the darker hours of the French Revolution when certain guiding spirits thought that they could dispense with science. When a revolutionary court passed swift sentence of death on the great chemist Lavoisier (see page 1628), the vice-president of the court, Jean-Baptiste Coffinhal, declared: "The Republic has no need of scientists." But this attitude was by no means general. Furthermore, men were not persecuted during the revolution because they were scientists but because for one reason or another they were thought to be enemies of the Government. Thus Lavoisier died on the guillotine because he was an aristocrat and a former tax farmer — a member of a private corporation to which the collection of taxes had been farmed out.

Many of the leaders of the French Revolution were vitally interested in science. They had to be for military reasons, if for no other. They needed gunpowder and weapons of war which only science and improved technology could supply in adequate quantities, and so they encouraged the men who could provide these sinews of war. Furthermore, they introduced a standardized and simplified system of measurements — the metric system — which has proved of great usefulness to scientists the world over.

A Commission on Weights and Measures was appointed in 1790 and worked for the next nine years to develop the important units of the metric system — the meter, the liter, the kilogram and the second (see page 4126). The commission adopted the meter as the basic unit of length. It was supposed to be a constant ten-millionth part of the quadrant line of the earth passing through Paris. The original measurement, it was later shown, was not quite exact; but the meter remains the basis of the metric system. Many years after the French Revolution, in 1870, scientists throughout the world agreed to accept three units of the metric system — the centimeter, the gram and the second — as international units for the scientific measurement of length, weight and time respectively.

Napoleon I, who took over the French Revolution and transformed the Republic into an empire, was deeply interested in science. He heaped honors on many scien-

tists whom we shall discuss in following chapters.

The creation of the metric system and the Industrial and Chemical revolutions were not the only striking developments in science and technology in the stormy period of the Age of Revolution. There were sensational advances in physics (especially in electricity); in paleontology, the science that deals with the life of past geologic ages; and in geology. W. Herschel and Laplace formulated influential theories concerning the nature and origin of the universe; Jenner developed a successful vaccine against smallpox; Malthus proposed his famous population theory. We shall discuss all of these matters in considerable detail in the pages that follow.

THE INDUSTRIAL REVOLUTION

The American Revolution has had innumerable chroniclers; the glory and the horrors of the French Revolution are just as familiar. But the story of the Industrial Revolution, whose impact on society has become more and more pronounced as the years go by, has less often been told.

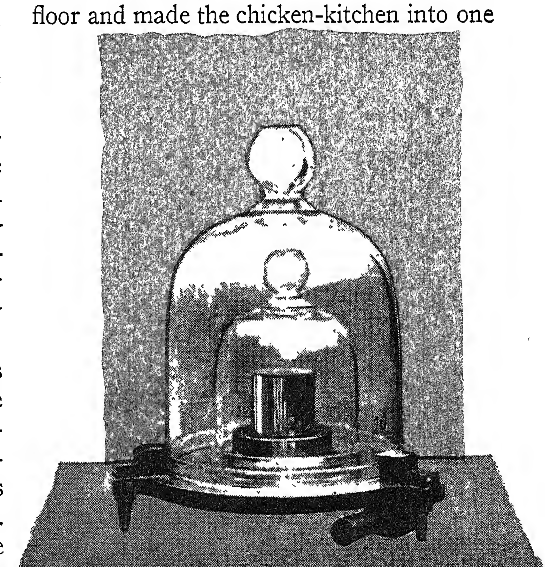
The Industrial Revolution evolved through a remarkable series of inventions, going back at least as far as the middle years of the eighteenth century. Power machinery was substituted for hand tools; the factory system first supplemented and then replaced the domestic system of work; and industry gradually assumed the form that is familiar to us.

The basic drive behind the Industrial Revolution was production. By the use of labor-saving machinery it became possible to produce far greater quantities of goods — for example, cloth — than earlier generations had deemed possible. We of the twentieth century are so much the children of the Industrial Revolution that we sometimes forget how differently men lived before they learned how to harness power and set the forces of nature to do the heavy work of the world.

The men who invented the machines that made the Industrial Revolution were not so much scientists as artisans — carpenters, weavers, millwrights and instrument-makers, with a few mathematicians and clergymen thrown in for good measure. But the men who were chiefly responsible for carrying forward the Industrial Revolution were businessmen, capitalists and entrepreneurs (risk-takers). You can compare them with the merchant adventurers of earlier centuries, who had supported scientific exploration. (See the Age of Discovery, pages 784-87.)

From the outset these new industrialists were aware of the need for science and research in the technological development of industry. Here, for example, is part of a letter written in 1780 by Matthew Boulton, an English manufacturer:

"Chemistry has for some time been my hobby-horse, but I am prevented from riding it by cursed business, except now and then of a Sunday. However, I have made great progress since I saw you and am almost an adept in metallurgical moist chemistry . . . I have annihilated William Murdock's bed chamber, having taken away the floor and made the chicken-kitchen into one



National Bureau of Standards

The standard kilogram, at the National Bureau of Standards in Washington, D.C. The kilogram is a unit of the metric system, established by French scientists in the hectic days of the Revolution.

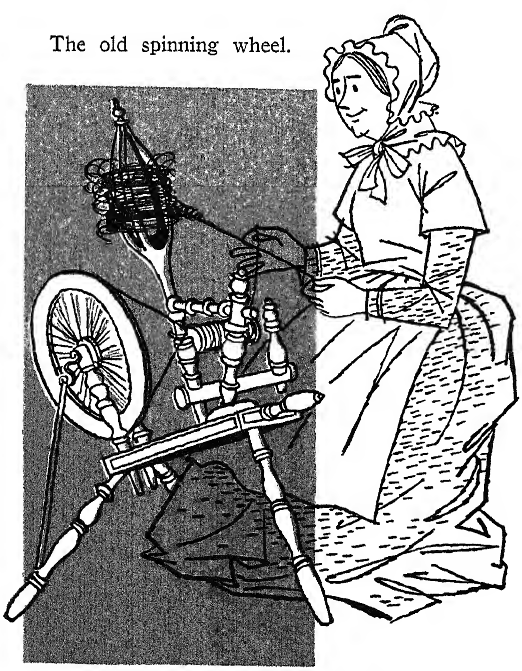
high room covered over with shelves, and these I have filled with chemical apparatus. I have likewise set up a Priestleyan water-tub [a pneumatic trough; see page 1625] and likewise a mercurial tub for experiments on gases, vapors, etc., and next year I shall annex to these a laboratory with furnaces of all sorts, and all other utensils for dry chemistry."

The keen scientific interests of businessmen like Boulton and Josiah Wedgwood, of the famous pottery family, drew them to associate with scientists like Priestley in little provincial clubs, such as the Lunar Society of Birmingham. They were eager to apply the methods and discoveries of science to the advance of industry.

It was in England that the Industrial Revolution began. One reason was that England possessed at home important raw materials like coal, iron and wood. Other important materials, like sugar and cotton, were available in her colonies and could be collected from overseas by the active British merchant marine. The political and economic doctrine of *laissez faire* (let them do as they please) also favored business enterprise in England, as did the accumulation of capital.

The Industrial Revolution began with certain ingenious inventions — machines — that made it possible for one pair of hands to do the work of many. Its effects were greatly heightened when steam power to operate the machines became available.

The old spinning wheel.

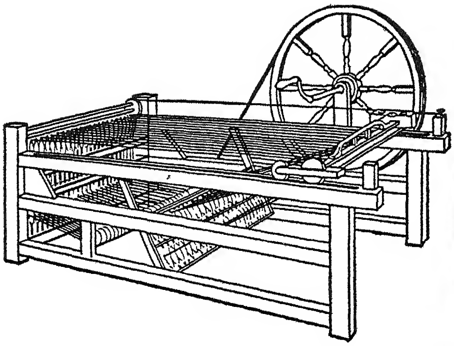


The gradual development, in eighteenth-century England, of machines that would do the work of many pairs of hands is well illustrated in the important textile industry. From the days of Homer until about the third decade of the eighteenth century, there had been only two basic improvements in the method of making cloth. The first of these was the use of water power to full cloth. (Fulling means to thicken cloth by means of moistening, heating and pressing.) Before this, the cloth had generally been put in a shallow stream and had been trod by the bare feet of children. The second improvement was the substitution of the spinning wheel for the distaff. With the wheel it was possible to spin much more rapidly than with the distaff, but the spinner could still work only one thread at a time.

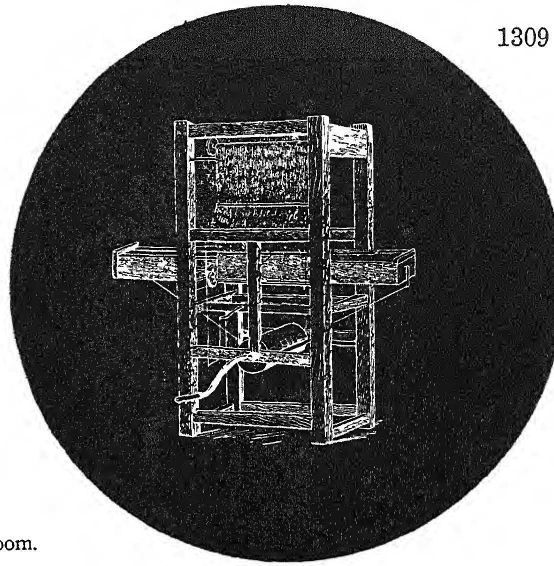
The flying shuttle, invented by John Kay

The first important invention in the eighteenth century was the flying shuttle, introduced by John Kay about 1733. The shuttle, thrown across the warp threads of a hand loom, came back automatically; it made it possible for one man to do the work formerly done by several. This speeded up the weaving process so much that the hand spinners could not keep up with the flying-shuttle weaver. It required the work of from five to ten spinners, each spinning a single thread, to keep a single weaver occupied.

In the typical one-thread hand-spinning wheel, the spindle was in a horizontal position as it turned. A spinning wheel that had been knocked over one day caught the eye of James Hargreaves, a spinner. He observed that both the wheel and the spindle continued to turn; only now the spindle was in a vertical position. It suddenly occurred to Hargreaves that if a number of vertical spindles were set up, more than one thread could be spun at the

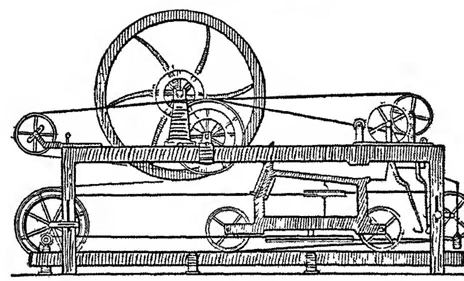


The spinning jenny of James Hargreaves.



Edmund Cartwright's power loom.

Samuel Crompton's spinning mule.

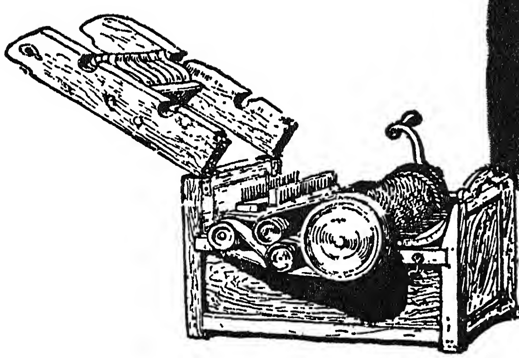


same time. Hargreaves went to work on the problem and at last developed a spinning machine with a number of spindles; he called it a spinning jenny. In the earliest machine, invented about 1765, there were eight spindles; in later models there were as many as eighty.

The next important improvement was in the quality of thread that could be spun and woven. This was the work of Richard Arkwright (1732–92), an energetic inventor and a keen businessman, who rose from barberdom to knighthood. In 1769 he invented the water frame, so called because it was operated by water power. In this machine, cotton thread was passed through two sets of rollers. The second set was driven at a higher rate of speed than the first; it spun the thread thin and hard, so that it could be used for warp as well as weft threads. Soon afterward Samuel Crompton, a poor spinner, worked out a way of putting Hargreaves' jenny and Arkwright's water frame together in a single machine that could draw out and twist a superior quality of thread. This hybrid invention was given the name of spinning mule.

As a result of all these improvements in spinning machinery, the relationship between spinners and weavers was now reversed; the spinners could produce much more yarn than could be woven into cloth. It was clear that the weaving process needed speeding up. This was brought about by the invention of the power loom by an English clergyman, Dr. Edmund Cartwright (1743–1823), who up to the age of forty had never seen a loom in operation. In a letter written to a friend, he has told the story of the invention:

"Happening to be in Matlock in the summer of 1784, I fell in company with some gentlemen of Manchester, when the conversation turned on Arkwright's spinning machinery. One of the company observed that as soon as Arkwright's patent expired, so many mills would be erected and so much cotton spun that hands could never be found to weave it. To this observation I replied that Arkwright must then set his wits to work to invent a weav-



Brown Brothers

Above, Eli Whitney. At the left is shown his famous cotton gin

ing mill . . . The Manchester gentlemen unanimously agreed that the thing was impracticable . . . I controverted [denied] the impracticality of the thing by remarking that there had lately been exhibited in London an automaton figure which played chess. 'Now you will not assert, gentlemen,' said I, 'that it is more difficult to construct a machine that shall weave than one which shall make all the variety of moves which are required in that complicated game.' [The automaton that played chess was a fraud; there was a man inside it!]

"Some little time afterward . . . it struck me that as in plain weaving there could be only three movements, which were to follow each other in succession, there would be little difficulty in producing and repeating them. Full of these ideas, I immediately employed a carpenter and a smith to carry them into effect. As soon as the machines were finished, I got a weaver to put in the warp, which was of such material as sail cloth is made of. To my great delight a piece of cloth, such as it was, was the product."

Cartwright completed his invention in 1787. His early power looms were not particularly successful; the inventor's task was complicated by patent litigation, piracy and the fierce opposition of the weavers, who feared that they would lose their jobs. The power loom was perfected, however, in due time and came into general use. It is not certain that Cartwright was the first man to develop a *successful* power loom; credit is sometimes given to John Austen of Glasgow. At any rate, once the loom began to function regularly, the output of spinners and of weavers was more or less in balance.

Another difficulty now arose: there was not enough raw cotton for the highly effective new machines to spin and weave. There was plenty of cotton in the fields, but it took a man a whole day to remove the seeds of a single pound of cotton. This problem was solved in the United States by a young Yale graduate from Connecticut, Eli Whitney (1765–1825). In the year 1793 he had been visiting the Georgia plantation of Mrs. Nathanael

Greene, widow of a famous general of the American Revolution. Mrs. Greene had been greatly impressed by the ingenious way in which the young man had mended and improved a broken embroidery frame. That evening she suggested that he try his hand at the difficult problem of removing seeds from cotton fiber.

With the help of Phineas Miller, the plantation manager, Whitney obligingly set to work on the problem. He soon solved it by inventing the cotton gin. ("Gin" is the abbreviated form of "engine.") In this machine, cotton was fed into a hopper and dropped to a steel grid. Hooked teeth in a revolving drum passed between the bars of the grid; these teeth seized the fibers and drew them through narrow slots while the seeds fell into a separate bin. With the gin one man could clean two hundred pounds of cotton a day. Cotton-textile manufacturers were thus assured of an almost unlimited supply of cheap raw material. "King Cotton" immediately came into his own on Southern plantations and in English textile mills.

Whitney returned to Connecticut and opened a factory for the manufacture of cotton gins. Unfortunately his original model had been stolen and its ideas freely pirated by Southern planters. Lawsuits in defense of his rights proved to be extremely costly.

Whitney makes a fortune through mass production

But Whitney was not daunted. In 1798 he took over a government contract that other manufacturers had considered "impossible": namely, to make and deliver ten thousand rifles within two years. He fulfilled the contract by means of mass production. His workmen made large numbers of accurately fitting parts separately and then they assembled the parts. The rifles were completed on time and Whitney made a fortune.

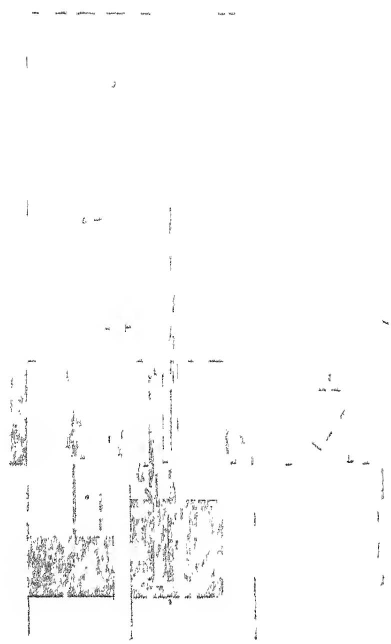
In the character of Eli Whitney we find the epitome of the quality once called "Yankee ingenuity," nowadays called "know-how." Through it the Industrial Revolution was gradually transferred to the American scene, where it became mass production. The key to mass production is the manufacture of standard, interchangeable parts that can then be quickly assembled into a finished product. Whitney was one of the first to employ mass production on a large scale and to show its future possibilities.

The problem of power for industry

The new inventions and ingenious machines of the eighteenth century opened up new vistas. But these inventions could not come into their own until men had succeeded in substituting for human muscles the power provided by the forces of nature. Windmills as a source of power had been well known for centuries, but wind power was too unreliable and inconsistent to work the new machinery. Water power, provided by wheels turning in a flowing stream, proved to be more satisfactory. But even water power had its drawbacks. Factories had to be built along rivers; if the rivers froze over in winter or became dry in summer, manufacturing operations had to be suspended. It was not until the steam engine was perfected that man had a really satisfactory source of power for his machinery — a source that would be available throughout the year.

The expansive power of steam had been known in antiquity. The Alexandrian physicist and inventor Hero had produced a toy steam engine, called an aeolipile (see page 359). About the middle of the seventeenth century, Edward Somerset, the second Marquis of Worcester, described a "steam fountain" or "omnipotent water-commanding engine," with which he claimed to have raised water to the upper part of a house. Later in the century, the Frenchman Denis Papin described a machine consisting of a piston driven in a cylinder by means of steam. An Englishman, Thomas Savery, took out a patent in 1698 on a primitive sort of steam engine, which was used to operate ornamental waterworks.

The first steam engine to be used in industry was an apparatus invented by



James Watt's steam engine.

Thomas Newcomen in the first years of the eighteenth century for the purpose of pumping water out of coal mines. In this machine the force of steam drove a piston upward in a vertical cylinder; the steam was then condensed by a jet of cold air and the resulting vacuum in the cylinder caused the piston to drop down and back to its starting position. The Newcomen engine pumped water out of coal mines after a fashion, but it was clumsy and inefficient at best. Even after it was improved in the course of the eighteenth century, it still gave a good deal of trouble.

In the year 1764 a Newcomen-type engine, which formed part of the collection of scientific apparatus at the University of Glasgow, got out of order. A dour professor of medicine and chemistry at the university, Joseph Black (see page 1625) turned the "fire engine" — as it was then called — over for repairs to young James Watt (1736–1819), who was employed by the university as an instrument-maker. Watt made some improvements in the engine and got it to run successfully.

He then turned to the problem of producing a new and more perfect steam engine. He observed, of course, that Newcomen's machine was most wasteful of fuel. As we saw, the steam had to be condensed under the piston so that the piston could be forced down by the weight of the air above it. Enormous quantities of heat were wasted in reheating the cylinder every time it was cooled down. Watt came to realize that this was due to a phenomenon that had been first described by Black: latent heat — that is, the extra hidden quantities of heat that are necessary to turn ice to water or water to steam before raising their temperature.

A steam engine, of course, is a device for turning heat into work. Watt and the other inventors of the time were concerned with the problem of increasing the *duty* of the steam engine. (The duty is the relationship between the quantity of fuel required to run an engine and the amount of work that it does.) Later Watt set out to figure the power of his engines — that is, their rate of doing work. He observed how much work an ordinary mill horse could do and he conceived the idea of rating his engines in terms of *horsepower,* a unit that we still use. Watt defined one horsepower as the equivalent of the work done in raising 33,000 pounds through a distance of one foot in one minute.

Watt succeeded in increasing the duty of the steam engine and in raising its horsepower rating. His chief innovation in making a practical and more efficient engine was to condense the steam without cooling the cylinder itself. This he accomplished by adding a separate condensing chamber, exhausted by an air pump, to the steam cylinder of the engine. After driving the piston, the steam was converted into a liquid in the condenser. Watt also provided a steam jacket around the cylinder and a similar arrangement on the cylinder head. All these innovations lessened the radiation of heat from the cylinder and brought about important savings in fuel.

Watt took out a patent on his new engine in 1769. Later he added many improvements. A double-action device, brought out in 1782, admitted steam alternately on each side of the piston so that

steam expansion rather than atmospheric pressure really did the work. Watt also provided a governor to regulate the speed of the engine and a gear mechanism for converting the back-and-forth motion of the piston into a rotary motion that would turn wheels.

In 1774 Watt entered into partnership with Matthew Boulton in order to manufacture his engine. It soon acquired European fame. At first the demand for these improved engines to pump water out of coal mines was so great that the output of the factory was destined exclusively for this purpose. It soon became clear, however, that the new steam engine could also be used to supply power for machinery other than mine pumps. Certainly it was far superior to the water wheel as a source of power. Factories using steam engines could be built anywhere; furthermore, they could be kept operating in every season of the year.

The rise of the machine-tool industry

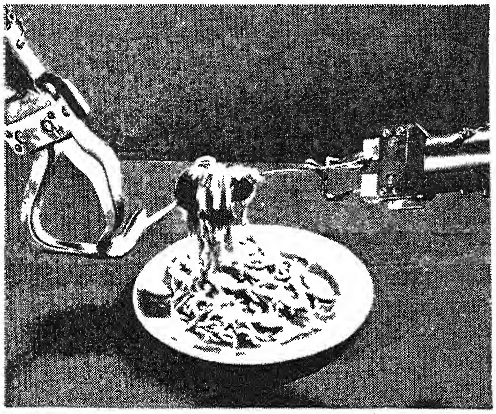
As more and more manufacturers began to turn to steam power to run their machines, the Industrial Revolution gained momentum, and mass production became more prevalent. A new industry arose: the making of machine tools, which were used to make machines. They included boring machines, planing machines, rolling mills, cutting tools, screw machines, automatic saws, hammers and punches. These tools were necessary to work and shape rapidly the metals — especially iron and steel — out of which the machines basic to the Industrial Revolution were fashioned. A whole machine-tool industry now grew up, especially in England, where the names of Maudslay, Bramah, Wilkinson and Smeaton are intimately associated with its origins. In the early days of the Industrial Revolution, many of the men whose jobs had been abolished by labor-saving machines found employment making machine tools.

By the year 1800 the Industrial Revolution was in full swing in England. In the years that followed, it was introduced into France and Germany and other countries of the Continent and in the United States. Its effects were heightened by the development, in the first half of the nineteenth century, of the steam locomotive and the steamboat. These transportation devices made it possible to collect raw materials and to distribute finished products far more effectively than ever before. The introduction of electricity on a wide scale in industry came later and marked another step forward.

Industrial revolution often brought social revolution in its wake. These effects were first seen and greatly lamented in England. The benefits brought about in that country by the immense increase in production were unequally distributed. Businessmen often profited greatly; the working class sometimes did not. The use of machinery permitted the use of semiskilled labor, often supplied by women and children; it rendered valueless the skills acquired by many handworkers. Furthermore, the new machines brought about a sharp distinction between employers and workers. These machines and the steam engines that ran them were too expensive to be owned by individual workers. Machinery and workers, therefore, had to be brought together in factories, where the building, the machines and the materials were owned by others.

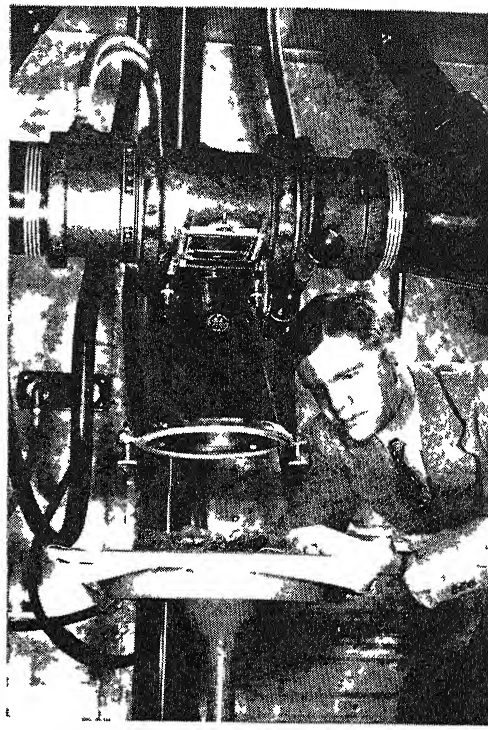
All in all, whatever its initial effects may have been, the Industrial Revolution has brought increased benefits to all. As production has increased, more goods have been made available. As wages have gone up and the hours of employment have become fewer, more workers have been able to afford these goods and they have had greater leisure with which to enjoy them. Furthermore, as industry has become more highly developed, it has availed itself more and more of scientific research. (See the chapter called Industry on the March, Volume 1.) Advances in scientific knowledge have led to advances in technology; and these have meant the rise of new industries—like the electrical industry—and the creation of millions of new jobs.

SCIENCE THROUGH THE AGES is continued on page 1625.



General Electric

When those who work with radioactive materials have to handle them by remote control, they use a manipulator provided with mechanical hands, like those illustrated above. Note that these hands are adept enough to twirl spaghetti on a spoon



Brookhaven National Laboratory

Botanist exposing trillium plants to X rays; later he will study changes brought about in their cell structure. Trillium is used because its chromosomes, carrying hereditary traits, are larger and easier to study than those of most other plants.

Iowa State College

Putting radioactive phosphorus on a plot about to be seeded. The mask and gloves of the experimenter minimize the danger of radioactivity; the panels prevent winds from blowing away the fertilizer.

WHAT THINGS ARE MADE OF

The Revolution of Radioactivity that Supposes Everything Compounded of the Same Ultimate Material

THE SECRET OF THE INFINITELY SMALL

WE now come to the most interesting subject of radiant matter; but, before we can understand the full significance of radioactivity, we must look at the manner of its discovery and consider its relationship to kindred phenomena.

In the first place, let us observe for a moment the common forms taken by matter, and the relationship between these forms. As we all know, we meet with matter either in solid, liquid or gaseous form. But it is not always recognized that for the elements and very many compounds, these forms have no real importance, and vary with the thermal condition of the substance We talk of water and mercury as liquids, and of iron and gold as solids, and of oxygen and nitrogen as gases. But the difference in terms of the common scientific theory of matter is just a difference of the distance between their molecules, and really amounts to little more than the difference between snow lying loosely on the ground and snow squeezed into a snowball, and to no more than the difference between steam and water. In a gas the molecules are so loosely compacted that they can fly about, and go for a certain distance without collisions. In a liquid they are loosely disposed, so that they easily slide over each other. In a solid they are packed together, so that they have not much room to move.

The nitrogen molecules in this room are flying about at a rate of more than a quarter of a mile a second; the oxygen molecules go almost as fast; and any molecules of water vapor go considerably faster, and every second each molecule collides millions of times with its neighbors. In like manner the molecules of all gases fly about and constantly collide with each other.

The molecules of liquids are not so mobile, but even the molecules of liquids are in motion. The molecules in a drop of water are as active as a swarm of bees, and between the molecules there is plenty of room. The amount of room can be demonstrated by adding a soluble salt to water. It will be found that the bulk of the solution is less than the sum of the two volumes, and therefore the molecules of the salt must have found accommodation somewhere in the space between the molecules of the water.

Even in solids there is a movement of molecules and, although every molecule has a place, which it fairly well keeps, it is not at rest any more than a molecule of a liquid or a gas, but has a certain mean position about which it is always vibrating and remaining near, and it is kept from losing that position by the action of the surrounding molecules.

But even in a solid the molecules do not always retain their mean position. To test this diffusion of solids Sir William Roberts-Austen prepared two pieces of gold and lead with one surface on each accurately planed. Having clamped the two metals together, flat surfaces in contact, and having kept them for four years at a fairly constant temperature, he found appreciable quantities of gold had penetrated one-fifth of an inch into the lead.

What it is that makes the difference between solids, liquids and gases

The difference between a solid and a liquid and a gas, then, is essentially just a difference of the distance between individual molecules, with consequent difference in freedom of movement. If the molecules are far apart we have a gas; if nearer together, a liquid; if nearer still, a solid; and any substance which can exist as such in the three states can be changed from a gas into a liquid, and from a liquid into a solid, simply by bringing its molecules progressively closer together by cold and pressure, and can be reconverted from a solid into a liquid, and from a liquid into a gas, simply by progressively causing a separation of its molecules by heat. All such substances are potentially gas, liquid and solid, and the condition in which each happens to be is just a matter of heat and pressure.

We see these three states illustrated in water, which, within the limits of ordinary temperatures, changes from gas into liquid, and from liquid into ice. And we see the same versatility in many other substances when we subject them to changes of temperature and pressure. Thus when we heat mercury it volatilizes as a gas, and when we cool it down to -39.4° C. it becomes a solid. At ordinary temperatures air is a gas, but by pressure and cold, its molecules may be gathered together into a liquid or a solid.

An astonishing scientific forecast made by the genius Michael Faraday

Matter then is well known and well understood in these three forms, but of recent years scientists have been compelled to take cognizance of a fourth more mysterious form, which may be distinguished as radiant matter. This fourth form was foreseen by Faraday, who nearly a hundred years ago, when but twenty-four, made an astonishing forecast.

"As we ascend," he wrote, "from the solid to the fluid and gaseous state, physical properties diminish in number and variety, each state losing some of those which belonged to the preceding state. When solids are converted into fluids all the variations of hardness and softness are necessarily lost. Crystalline and other shapes are destroyed. Opacity and color frequently give way to a colorless transparency, and a general mobility of particles is conferred.

"Passing onward to the gaseous state, still more of the evident characters of bodies are annihilated. The immense differences in their weight almost disappear; the remains of difference in color that were left are lost. Transparency becomes universal, and they are all elastic. They now form but one set of substances; and the varieties of density, hardness, opacity, color, elasticity and form, which render the number of solids and fluids almost infinite, are now supplied by a few slight variations in weight, and some unimportant shades of color. . . . If we conceive a change as far beyond vaporization as that is above fluidity, and then take into account also the proportional increased extent of alteration as the changes arise, we shall, perhaps, if we form any conception at all, not fall far short of Radiant Matter; and as in the last conversion many qualities were lost, so here also many more would disappear."

How Faraday's remarkable forecast was proved true by Sir William Crookes

About fifty years later, in 1865, it was found possible to get new spectra from ordinary elementary bodies by subjecting them to great heat, and similar spectra were obtained from elements in the sun and in certain of the stars. And these new spectra undoubtedly indicated a radical change in the nature of the gaseous elements, and were supposed by some to be produced by broken atoms. But the actual detection of radiant matter — of matter in a state neither solid nor liquid, nor gaseous — did not take place till some years later.

It may be said that Sir William Crookes was the first man to bring radiant matter within reach of laboratory methods, and to realize its deeper significance. He was studying the effects of electrical discharges sent through a glass tube almost com-

pletely emptied of air, when he met and recognized this fourth form of matter. A German scientist, J. W. Hittorf, had noticed that electric discharges through such a tube produced an exquisite glow in the tube, and Sir William Crookes was really investigating this glow. By ingenious methods he succeeded in making a much more perfect vacuum than had ever been made before, and succeeded in showing that the glow in the glass was probably caused by its bombardment by infinitesimally small particles which were discharged from the negative electrode. He found that these particles could be attracted and repelled by magnets, and that they therefore must carry electrical charges, and he found out other interesting facts about their behavior, but he did more than this, for, with the penetration of genius, he came to the conclusion that the particles were particles of matter in the fourth form foreseen by Faraday — that they were the basic matter of the universe.

A scientific epoch made by Faraday's forecasts and Crookes's discovery

Here are Sir William's very words:

"In these highly exhausted vessels, the molecules of the gaseous residue are able to dart across the tube with comparatively few collisions, and, radiating from the pole with enormous velocity, they assume properties so novel and so characteristic as to entirely justify the application of the term borrowed from Faraday, that of *Radiant Matter*. . . . In studying this fourth state of matter, we seem at length to have within our grasp and obedient to our control the little indivisible particles which, with good warrant, are supposed to constitute the physical basis of the universe. We have seen that in some of its properties Radiant Matter is as material as this table, whilst in other properties it almost assumes the character of Radiant Energy. We have actually touched the borderland where matter and force seem to merge into one another, the shadowy realm between the known and the unknown."

These words mark a scientific epoch.

Before long many of the acutest minds in the world were studying the characters of these particles, and many wonderful things about them were found out in many wonderful ways; and in 1897 Professor J. J. Thomson succeeded in proving that the particles have a mass only about $\frac{1}{1800}$ that of a hydrogen atom, that they move with tremendous rapidity, and that they carry charges of negative electricity equal to the charges carried by ions of hydrogen. The proved proposition that the particles have a mass only $\frac{1}{1800}$ that of hydrogen was plainly most revolutionary. Up to this time the smallest particles of matter known to science were atoms, and the smallest known atom was the hydrogen atom, and, lo, here was a particle with a little more than $\frac{1}{2000}$ the mass of a hydrogen atom. And it comported itself in the most astonishingly new ways, neither like a molecule in a gas, nor like a molecule in a liquid, nor like a molecule in a solid.

The unthinkable speed of the infinitely small particles of radiant matter

The fastest gaseous molecule we know is the hydrogen molecule in gaseous condition, and it flies somewhat more than a mile a second, or 60 miles a minute, or 3600 miles an hour. A cannon-ball can go about 2000 miles an hour, for a short distance. The earth rushes round the sun at the rate of 19 miles a second, or 1140 miles a minute, or 68,400 miles an hour. Arcturus goes faster still, about 100 miles a second, while the spiral nebula in Cetus (N. G. C. 584) makes about 1125 miles per second.

These are all great speeds, yet all these racers are caterpillars and tortoises compared with the primary particles, for these flash along at the rate of 19,000 miles a second and more. They can do, therefore, about three times as many miles in a second as the nimble hydrogen molecules can do in an hour. Of all rapid things we know, only light, heat and electric waves move faster. But with all this speed these electrons do not travel far; their velocity is reduced to zero by a three-inch trip through air.

The marvelous heat-producing and penetrating power of these tiny electrons

Little wonder that these little particles, which have been named *electrons*, or *corpuscles*, can make the glass glow. And they can cause many substances to phosphoresce. Barium platino-cyanide and calcium tungstate phosphoresce radiantly under the impact of the electrons. Naturally the electrons heat what they hit; and if a stream of them be focused on a particular point their impact will render platinum white-hot, and will melt glass or char a diamond.

Though the electrons are so small their momentum is comparatively great, and when they strike an easily movable object they tend to move it. In some way also they are able to move and rearrange the molecules in various substances. Thus, if the electrons impinge on rock salt, the rock salt becomes a beautiful violet color, and certain gems are changed in color if battered by the electrons. One of the most wonderful properties of the electrons is their power of passing through solid substances. The power of penetration of the electrons depends on the density of the substance; the less dense the substance, the more penetrable is it to the electrons. Taking advantage of this fact, it is possible to make a little window of aluminum (a metal of small density) in the vacuum bulb by means of which the electrons can escape to the outer air.

How these tiny and nimble electrons make the air a conductor of electricity

We have stated that the electrons carry an electric charge equal to the charge carried by an ion of hydrogen. Now, this is a very extraordinary thing that particles, having only $\frac{1}{1800}$ the mass of hydrogen, should yet be able to carry an equal electric charge; and, as we shall see later, it is supposed by some that the electron is all electricity together — hence the name electron, that has been given to it. A very characteristic property of the electrons is their power of rendering gases, such as, for instance, the air, conductors of electricity.

Thus, if we have a charged body insulated from the earth, it will retain its charge of electricity for a long time, but if a few electrons are shot through the air around it, the air becomes a conductor of electricity, and the charge leaks away.

Since they carry electric charges, the electrons can be deflected from their course by magnets; and the magnetic force required to deflect them to a definite degree helps us to find out their mass and velocity relative to their electric charge.

Finally, the electrons have a very interesting property, the property of condensing vapor in the form of drops. We shall see later that rain-drops and mist-drops always gather round specks of dust in the air, which serve as points of condensation. The electrons can take the place of dust in this respect; and if a stream of electrons be passed through humid air a mist of fine drops at once forms, and the drops gradually descend to the ground. This property is of particular interest, for by means of it the number of electrons can be calculated, and thus the electrical discharge of each can be ascertained. The calculation is made in the following ingenious way. From the rate of the descent of the drops, their size can be estimated; and so, if we measure the total amount of water condensed, we can find out the number of individual drops of that size required for its making, but the number of the drops gives the number of electrons that condense them, and thus the number of electrons is ascertained.

Let us now recapitulate the properties of the electrons we have mentioned:

They have $\frac{1}{1800}$ the mass of a hydrogen atom.
They carry the same electric charge as a hydrogen ion.
They fly at the rate of about nineteen thousand miles per second.
They are deflected from their course by a magnet.
They render gases conductors of electricity.
They heat bodies they hit.
They cause molecular change in some bodies they hit.
They cause phosphorescence in some bodies they hit.
They serve as centers of condensation for moisture in the air.

A discovery that has shaken the foundations of chemistry like an earthquake

These, then, are the most important characters of the electrons, and certainly neither the molecules of gases nor of liquids nor of solids have similar characters.

But let us now look at the origin of these wonderful particles. Where exactly do they come from, and why? They radiate from the negative electrode in the vacuum tube, and they are certainly derived from it. But they have a mass nearly $\frac{1}{2000}$ of the mass of hydrogen atoms, therefore they are certainly neither whole molecules nor atoms, and must be bits of atoms. There, then, as we said before, is a most revolutionary fact; it shook the foundations of chemistry like an earthquake. For the atom was considered the most indivisible and indestructible thing in the universe. Newton held that the atoms, "being solids, are incomparably harder than any porous bodies compounded of them, even so very hard as never to wear or break in pieces, no ordinary power being able to divide what God Himself made in the first creation." Dalton maintained that "we might as well attempt to introduce a new element into the solar system as to create or destroy a particle of hydrogen." Clerk-Maxwell eloquently affirmed: "Natural causes, as we know, are at work which tend to modify, if they do not at length destroy, all the arrangements and dimensions of the earth and the whole solar system. But though, in the course of ages, catastrophes have occurred, and may yet occur, in the heavens, though ancient systems may be dissolved and new systems evolved out of their ruins, the molecules out of which these systems are built — the foundation-stones of the material universe — remain unbroken and unworn."

The supposed indivisible shown to be only a thing of tiny fragments

A few wise men, it is true, were not so dogmatic, and, reasoning on philosophic principles, were of the opinion that the different elements were formed by combinations of still smaller ultimate homogeneous units; but the general opinion of scientists was that atoms were quite indivisible and indestructible. No wonder. All chemical and natural changes seemed to show it. An atom of hydrogen belched from Vesuvius might drift in a cloud to the Gulf of Mexico, might fall in a thunder-shower on a sugar plantation in Jamaica, might become part of the sugar in a cup of tea, and might pass thence from the liver of a man into his muscles, and from his muscles into the muscles of a worm, and from a worm into the crop of an early bird, and undergo a million other vicissitudes, and yet, so far as science could discover, one was bound to believe that the hydrogen atom would remain exactly the same in size, weight, capacity for speed and all other characters. No form of violence, no chapters of changes, seemed able to disrupt these foundation-stones of the universe.

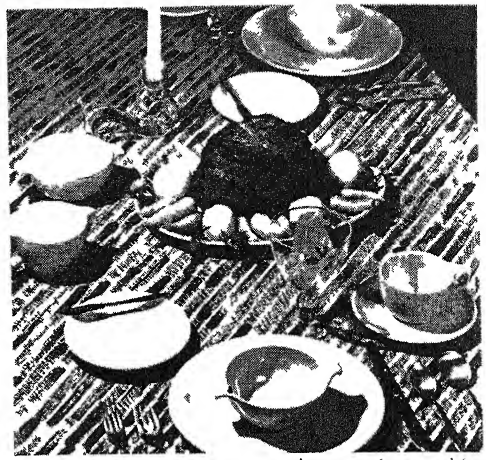
And yet here were fragments of the foundation-stones flying about inside a vacuum tube and making the glass blue and green. There was no doubt about it; there they were flying about nineteen thousand miles a second, condensing moisture, rendering substances phosphorescent, and doing other undeniable things.

All electrons have the same mass, velocity and electric charge

But even more revolutionary discoveries were to be made. It was found that, no matter what substance is used as the negative electrode, the electrons that are discharged from it always have exactly the same mass, the same velocity and the same electric charge. In the first flush of this sensational discovery Crookes made the rather extravagant claim that electrons constitute the basic material of the universe. Today no reputable scientist would support that claim. We realize now that electrons are by no means the only subatomic (less than atom) particles. There are protons, each with a positive charge, neutrons, with no electric charge at all, mesons and still others. We have shown in another article (Inside the Atom) how such particles fit in the atom's structure.

Bakelite Div, Union Carbide and Carbon Corp

This inflatable boat made of vinylite plastic sheathing makes bathing a pleasure for the young



American Cyanamid Co

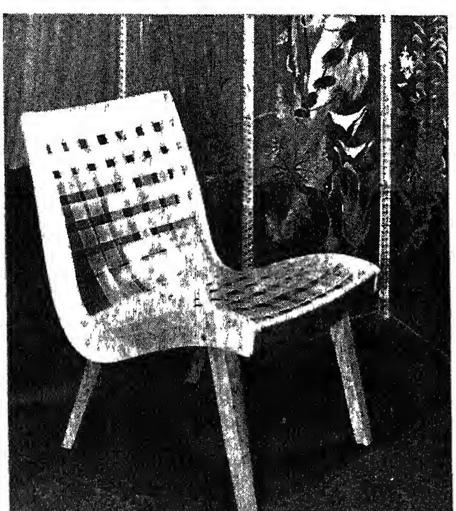
These dishes, made of melamine are unusually attractive and they are just about indestructible

THOSE VERSATILE PLASTICS

The word plastics, properly speaking, refers to all the substances that can be readily molded, including materials like rubber, clay and metal Today, however, when we speak of plastics, we generally have in mind a great variety of synthetic substances that are prepared in chemical laboratories In our article on Plastics, in Volume 2, we explained how plastics are classified and we described some of the processes used in manufacturing them

We all come in constant contact with objects made of plastics costume jewelry, hardware, tableware, toys, electrical appliances, automobile parts, articles of clothing and what not There is hardly a field of industry in which plastics do not serve, they are often used for appliances built to rigid specifications

The pictures in the following pages show some of the infinitely varied ways in which these wonder materials are employed



Left Du Pont, above, Westinghouse

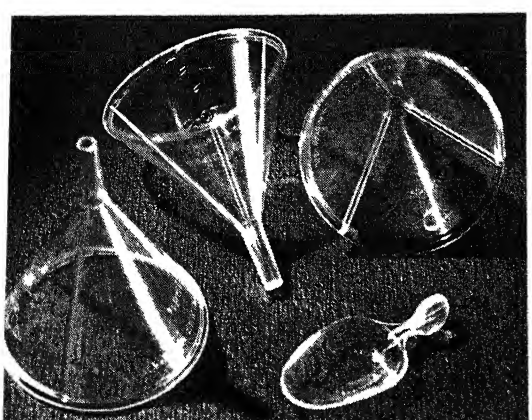
The back and seat of the chair at the left are made of strips of translucent nylon plastic sheeting Above micarta bearings ready for shipment

Monsanto Chemical Co

Lightweight eye shields, of cellulose acetate

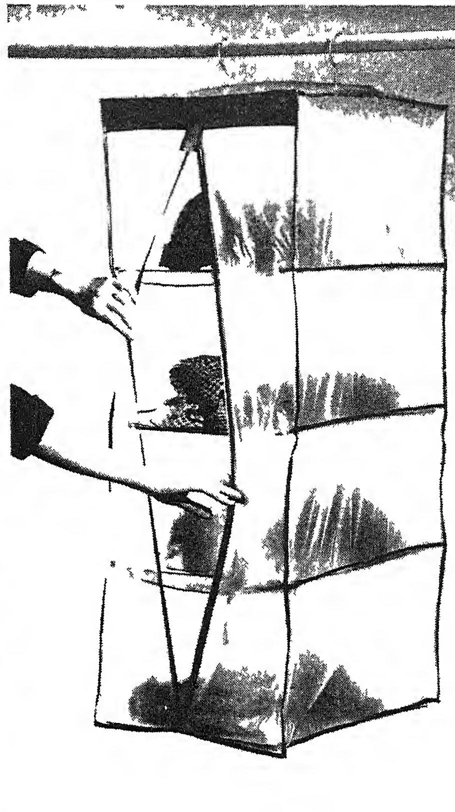
Bakelite Div Union Carbide and Carbon Corp

The miniature mixer, laundry washer and dishwasher shown above are all molded of styrene plastic an extremely versatile plastic material



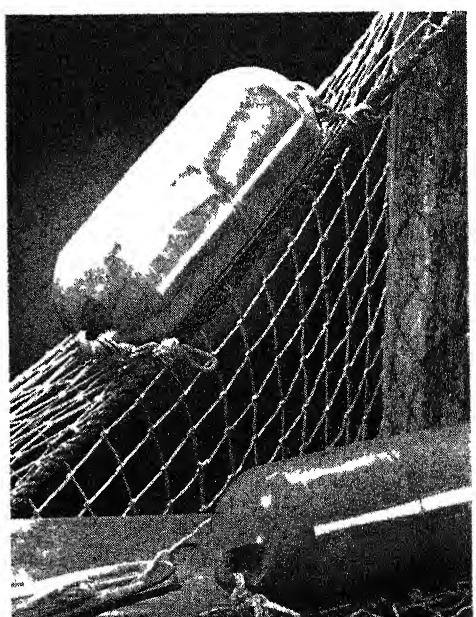
Above Dow Chemical Co , right Eastman Kodak Co

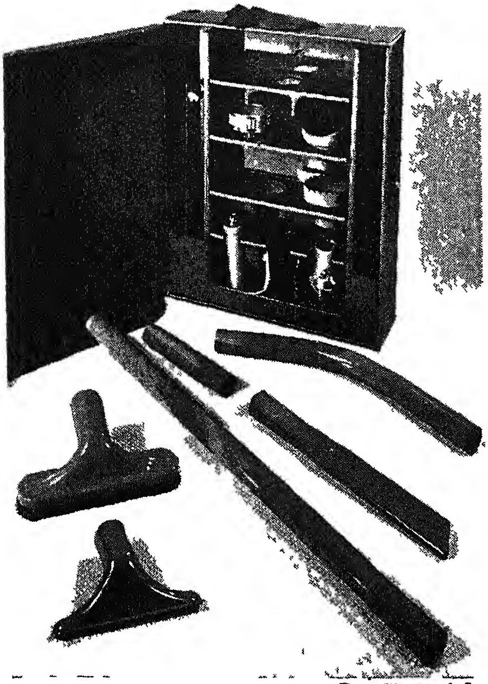
The medical spoon and the funnels shown above are of Styron The two Tenite floats at the right are lightweight but can withstand rough treatment



Bakelite Div Union Carbide and Carbon Corp

This unusual hatbox, made of vinylite plastic film can also be used for shoes and for other articles of apparel It keeps dirt and moths out



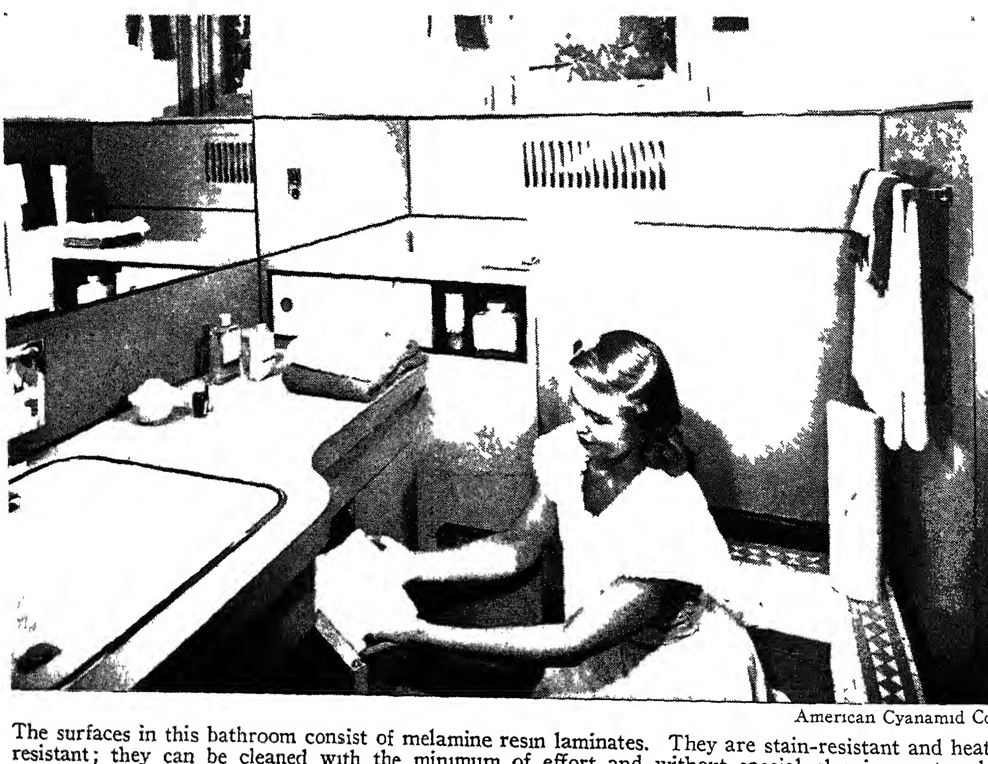


Dow Chemical Co.

Vacuum-cleaner parts made of gray Ethocel. There is no surface coating to chip or to wear off.

Upper photo. Dow Chemical Co ; lower photo Du Pont

Above: tough Saran film, used to package various foods. Below it is shown a knife made of Lucite



American Cyanamid Co.

The surfaces in this bathroom consist of melamine resin laminates. They are stain-resistant and heat-resistant; they can be cleaned with the minimum of effort and without special cleaning materials.

HERBERT SPENCER'S GOSPEL

How Mind and Body are Being Perfected
Through Infinite Times by Unfoldings from Within

CAN WE NOT SAY THE ENERGY IS DIVINE?

NEGLECTED and ridiculed, Lamarck passed away twenty years after his great work was given to the world. Thirty more were to elapse before the publication of the "Origin of Species" in 1859, exactly half a century after the *Philosophie Zoologique.* In that interval men were continuing to feel for some theory of evolution, and two obscure authors independently advanced what was essentially the theory of natural selection. Cuvier died believing in the fixity of species, and Sir Charles Lyell published his epoch-making book on the "Principles of Geology," in which he established the evolutionary idea so far as the earth's crust was concerned, but not until many years later, under the influence of Darwin, did he discard his belief in the fixity of species, and their "special creation."

Meanwhile there had come upon the scene a young engineer whose name is among the most illustrious in the history of science, and whose fame is steadily increasing as the years justify him. This was the unique figure of Herbert Spencer, the philosopher of universal evolution, whose championship of cosmic evolution, when it was discredited by the astronomers of the day, has already been referred to in another section of this work. Spencer was an evolutionist by instinct, we may almost say; and his discovery of his own discovery was made when he had occasion to read over for republication a number of essays, on all manner of subjects, which he had contributed to the reviews when he began to write. The idea of evolution was implied in all of them.

Spencer was, from first to last, interested above all in man, his conduct and nature and destiny and duty. He did not come to biology by the ordinary route. He went to no university, and never passed an examination. But he was intensely interested in political principles, and there he began. What was progress, and how did it happen? On this subject he wrote and pondered, recognizing already certain principles which are involved in organic evolution. Further thought made it clear that there is no law of progress in nature, in the sense of an irresistible, constant, continuous upward tendency in things. There is, in the living world, an orderly process of change, including change of species, which may result in what we call progress, or in what we call degeneration or retrogression. It is part of the general process of the universe, to which Spencer gave the name of "evolution".

It was man, as we have said, who was Spencer's chief concern, and it was through the study of the mind of man that he went on to organic evolution in general. The question is vital to the whole theory of evolution. Our whole idea of the universe is radically different according to whether we look upon the mind of man as a new and special creation, or as historically related to the mental manifestations of the lower animals. In his "Principles of Psychology," Spencer set himself to answer this question; and, though the mind of man is not the business of this section, yet the minds of men and of the lower animals are manifestations of life, so that the problem of the evolution

of mind must be considered here. The greater will be the profit if, at any later stage, in this or any other work, we are to study the mind of man himself; for only through evolution can that mind be adequately understood.

Spencer saw that the intellect of man has been formed "by and for converse with phenomena," to use his own words. In declaring this same truth as a cardinal part of his own teaching today, Bergson scarcely does justice to Spencer, who proclaimed it over sixty years ago. Spencer saw that the intellect is a natural product, an adaptation, to enable man to deal with the world and its phenomena. It has been shaped *by* converse with them and is meant *for* converse with them. This gives the intellect its effectiveness when dealing with practical things, as Bergson points out today, and it explains why the intellect finds itself in the presence of the Unknowable when it strives to pierce below phenomena, as Spencer pointed out long ago.

The great thinker who began to trace the history of the human mind

But if the intellect is a natural evolutionary product, its history must be traced; the evolution of mind is seen to be part of the problem of the evolution of life. We must have an evolutionary or genetic psychology. And of this, which guides the modern study of the mind at every step today, Herbert Spencer was the founder. Until his time, every psychologist and philosopher, without exception, had treated mind as he knew it — his own mind — as a thing without antecedents, called into being and indelibly minted by the hand of the Creator. We may perhaps think that this was only natural, since the theory of special creation was generally accepted. Yet it remains almost incredible that it should never have occurred to any thinker that it might be worth while to compare one mind with another. Even if we appreciate the influence of the belief that no animal possessed what could be regarded as a mind, even if we try to appreciate the point of view of the philosophers who regarded savages as degenerate beings, and the savage mind as merely a disfigured specimen of the human mind as it was originally created, it remains inexplicable that practically no one before Herbert Spencer should have thought it worth his while to study the mind of the child. He was the first man to realize effectively that mind has a history.

Spencer's theory that the mind has grown by traceable stages to what it is

All the psychologists before him took the adult mind of their own species and race, called it simply Mind, and argued therefrom. This was essentially, of course, the method of looking within, or introspection, which was supposed to be characteristic of psychology, and which is doubtless necessary to it. But Spencer saw that psychology must also be an objective science, studying specimens and varieties and types of mind, just as the geologist studies fossils, the astronomer stars, or the entomologist beetles. This it is which gives Spencer a unique position in psychology. He made contributions to the study of evolution in all its branches, but in psychology he was not only a pioneer by reason of one great idea, but was also a specialist — a master alike of principles and details.

The evolutionary psychology teaches that the mind of the adult civilized man, the mind of the savage, and the child, and the minds of animals are related evolutionally, and must be studied together if any of them is to be understood. Doubtless many savages are degraded, and do not represent earlier stages of the civilized mind, but other so-called savages do represent such stages, as do the child and the animal. We are invited, therefore, to believe that the fully developed and adult mind, even of such creatures as ourselves, is a product of universal and organic evolution, in parallel with our bodies, of which we are willing to admit so much.

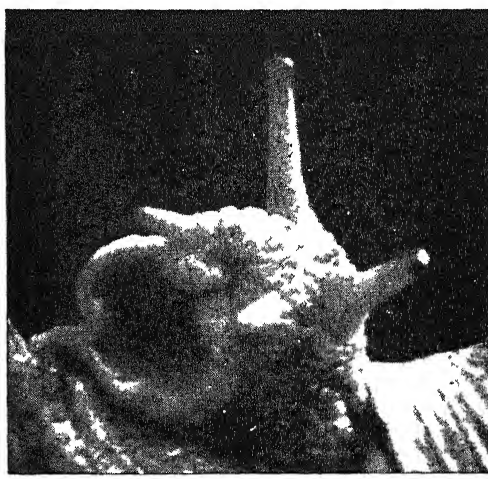
Let us consider the history of the individual mind, and it will prepare us for the Spencerian assertion as regards the race.

We might take the mind of a dog or an ape for the purpose, but we may as well consider our own case. In considering the history of the individual mind we are forced back, by logic which none can now dispute, to the moment at which the germ-cells derived from the two parents fuse within the body of the mother. At that moment the new individual begins, and already exists as an individual. We all agree that the mind of the adult develops from the mind of the child, nor can we deny that it must develop from the mind of the new-born baby. But science will not let us stop there. We have no choice but to admit that the mind of the adult is developed from mental possibilities and potentialities found not merely in the child, or in the infant, or in the unborn babe, but in the single cell which is the first stage of the new individual. It is hard to believe. But is not the development of the adult body from this single cell hard to believe? And yet that undoubtedly happens. Furthermore, it must be remembered that the new cell which is to give rise to a new individual, and in which are contained the potentialities of that individual's mind, is itself the product of two other cells, each of which was as certainly alive as it is, and each of which is the living bearer of the mental characteristics which everyone sees and admits to be transmitted from parent to child. Thus, to reflect upon the history of the individual mind in any adequate measure is to encounter indisputable facts at least as amazing as — indeed, by the rapidity of the development, much more amazing than — the long-disputed facts of the evolution of the racial mind. In other words, the evolutionary assertion as to the history of the mind of man is no whit more incredible than the known facts as to the history of the individual minds of individual men.

Thus prepared by contemplation of the daily marvel which is familiar to every parent, the evolution of the individual mind, we need not fear to lose the doctrine that the human mind is a special creation, lest we should have to believe the incredible.

We may take the case of vision, the most important, and perhaps almost the most ancient, of the senses. Sensation is, of course, as much psychical as physical; and in this instance the evolution of the sense called vision is clearly parallel with that of the physical structure we call the eye. Here is Tyndall's account, from his celebrated Belfast address, of the Spencerian theory of the evolution of vision:

"In the lowest organisms we have a kind of tactual sense diffused over the entire body; then, through impressions from without and their corresponding adjustments, special portions of the surface become more responsive to stimuli



THE STRUCTURALLY PRIMITIVE EYES OF THE SNAIL

than others. The senses are nascent, the basis of all of them being that simple tactual sense which the sage Democritus recognized 2300 years ago as their common progenitor. The action of light, in the first instance, appears to be a mere disturbance of the chemical processes in the animal organism. By degrees the action becomes localized in a few pigment-cells, more sensitive to light than the surrounding tissue. The eye is here incipient. At first it is merely capable of revealing differences of light and shade produced by bodies close at hand. Followed as the interception of the light is in almost all cases by the contact of the closely adjacent opaque body, sight in this condition becomes a kind of 'anticipatory touch.'

The adjustment continues; a slight bulging out of the epidermis over the pigment granules supervenes. A lens is incipient, and, through the operation of infinite adjustments, at length reaches the perfection that it displays in the hawk and eagle. So of the other senses they are special differentiations of a tissue which was originally vaguely sensitive all over."

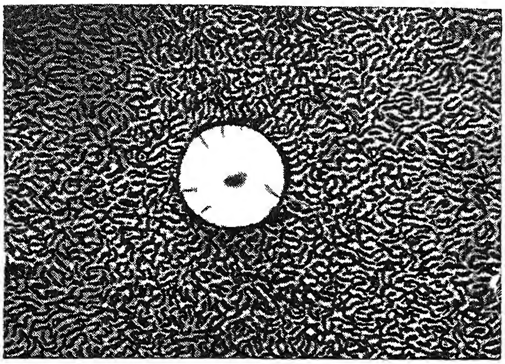
Let us not suppose that such a statement explains *how* life makes its adjustments, which, as Bergson points out, are not repetitions of the environment, but replies to it Nevertheless, the passage shows how the evolutionary principle may be applied in the realm of the senses and of the mind. Spencer has more to say about the sense of touch, as primitive. He points out that the parrot is the most intelligent of birds, and its tactual power is also greatest. From this sense it gets knowledge unattainable by birds which cannot employ their feet as hands. Similarly, the extraordinary opportunities of touch afforded to the elephant by its trunk are the basis of its sagacity Lastly, in the anthropoid apes and in man there is great development of touch, which brings knowledge and feeds and trains the intelligence

These are the kinds of argument which the modern psychologist has in mind when he urges the necessity of a great extension of manual training in the education of children. On their purely scientific side they contribute to a genuine psychology, which traces the origin of the mind, both in the development of the individual and in the evolution of the race.

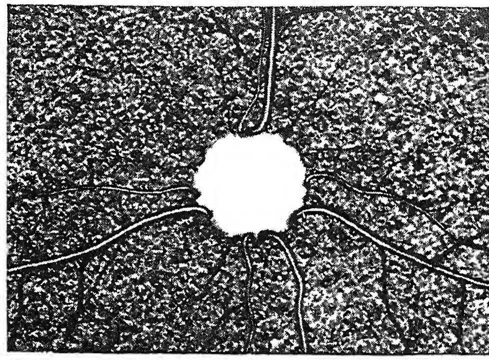
In the attempt to explain the racial development of mind, Spencer invoked, as seems the most reasonable, the principles of Lamarck. He observes the extraordinary skill of the chick, which, ten seconds after coming out of the egg, can balance itself, run about and pick up food. How did the chick learn this very complex coördination of eye, muscles and beak? It has not been individually taught, its personal experience is *nil*, but, according to Spencer, it has the benefit of ancestral experience. According to Spencer, the age-long experience of the race is registered in the structure of the young individual — which is, of course, Lamarckism. Thus he argues, in a celebrated passage, that the human brain is the "organized register of infinitely numerous experiences received during the evolution of life, or, rather, during the evolution of that series of organisms through which the human organism has been reached. The effects of the most uniform and frequent of these experiences have been successively bequeathed, principal and interest, and have slowly mounted to the high intelligence, which lies latent in the brain of the infant. Thus it happens that civilized man inherits from twenty to thirty cubic inches more of brain than the Papuan. Thus it happens that faculties, as of music, which scarcely exist in some inferior races, become congenital in superior ones. Thus it happens that out of savages unable to count up to the number of their fingers, and speaking a language containing only nouns and verbs, arise at length our Newtons and Shakespeares."

As we have seen already, modern biology finds itself bound to reject this theory of inheritance, and that refusal is, of course, a very serious matter for the psychology of Spencer We may believe that mind is an evolutionary product, as he taught; we may believe that the working of an instinct is a complex reflex action, and has been evolved out of the simple reflex responses to light and pressure, and so forth, which we find in the humblest forms of life. But though we learn from him in these respects, and accept the idea that our study of mind must be comparative, like our study of body, since both are evolutionary products, yet we are compelled to reject his explanation of the origin of instincts in ancestral habits, which have gradually become accumulated and ingrained in the very tissue of the offspring. The evidence against this view, and against any such inheritance in the realm of mind, is now overwhelming. It is necessary, also, to add that we have no other explanation which satisfies the mind to offer in place of Spencer's.

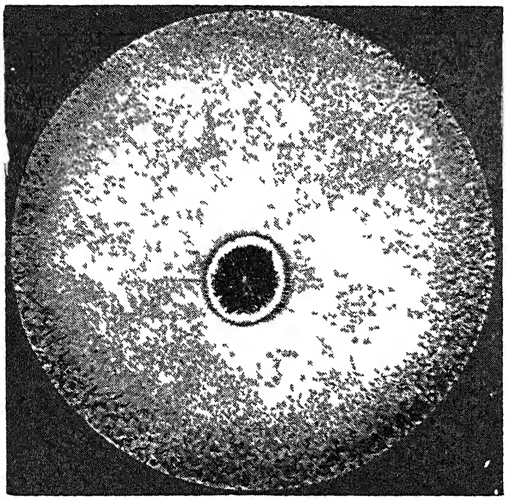
STORIES OF ADAPTATION READ IN EYES



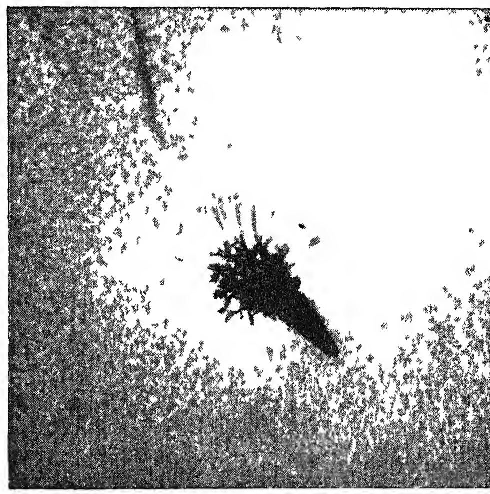
THE EYE-GROUND OF THE AFRICAN ELEPHANT



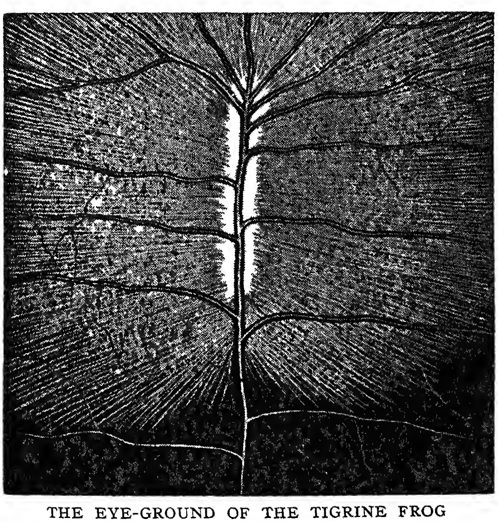
THE EYE-GROUND OF THE AFRICAN LION



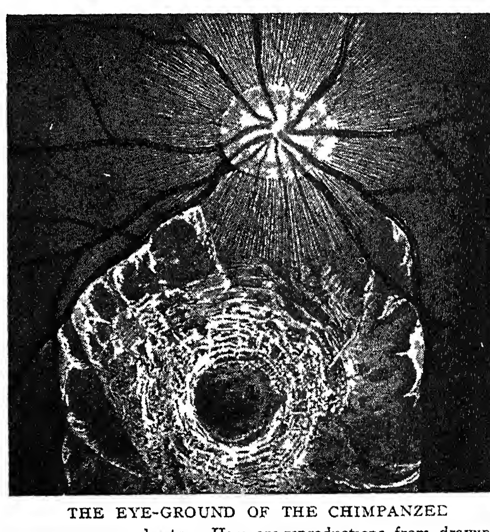
THE EYE-GROUND OF THE MISSISSIPPI ALLIGATOR



THE EYE-GROUND OF THE KIWI



THE EYE-GROUND OF THE TIGRINE FROG



THE EYE-GROUND OF THE CHIMPANZEE

Sight, evolved from touch, has become perfected in the eye with ever increasing complexity Here are reproductions from drawings by Mr Arthur W Head of the back inner wall of the eyes of six animals They include the elaborate eye of the chimpanzee, fully supplied with blood vessels, and showing, on the right, the part where vision is concentrated, the well developed eye of the African lion; the eye of a frog, with blood-vessels clearly visible, the protected eye of the Australian bird, the kiwi, and, much simpler and evidently of an earlier type, the inner eye-walls of the African elephant and the Mississippi alligator The series tell a story in evolution

Spencer's definition of life is almost the best yet framed In his view, "life is the continuous adjustment of internal to external relations" This idea of adjustment or adaptation is a cardinal one, and, all through evolutionary speculation and study, that is the great fact which we seek to explain. Spencer's definition does not profess, in itself, to offer any explanation, but it has the great merit of fixing on an essential fact of life, its continuous internal adjustment in reply to the changes and the demands of external circumstances. This adjustment, which proceeds alike in the realm of the living body and in the realm of mind, is a *positive* act on the part of life; it is indeed the essential act of life. Adaptation is its result, alike in the individual and in the race. The biologists who wish to explain everything by the mechanical Darwinian theory of natural selection, reject Lamarck's explanation of adaptation, both in the individual and in the race, and seek to explain the "continuous adjustment" of life to its circumstances by the theory that what is not adequately adjusted or adapted is wiped out by natural selection. This makes the negative process of rejecting the unadapted explain the positive fact of adaptation.

GORSE SEEDLING WITH TREFOIL LEAVES OF ITS ANCESTORS

On this fallacy let Bergson pronounce: "That adaptation to environment is the necessary condition of evolution we do not question for a moment. It is quite evident that a species would disappear should it fail to bend to the conditions of existence that are imposed on it But it is one thing to recognize that outer circumstances are forces evolution must reckon with, and another to claim that they are the directing forces of evolution. This latter theory is that of mechanism It excludes absolutely the hypothesis of an original impetus, I mean an internal push that has carried life, by more and more complex forms, to higher and higher destinies Yet this impetus is evident; and a mere glance at fossil species shows us that life need not have evolved at all, or might have evolved only in very restricted limits, if it had chosen the alternative, much more convenient to itself, of becoming rigidly fixed in its primitive forms."

Plainly, therefore, the evolution of life, and the "continuous adjustment" and adaptation of those forms which have survived, cannot be explained by pointing out that forms which were not adapted would become extinct; and if we are to find the source of the push or force which drives life on and is witnessed in its unceasing adaptations, we must go behind it to discover, in Spencer's words, "the infinite and eternal energy from which all things proceed."

Spencer's definition of life, which guides us in our interpretations at every stage, is contained in his great work on biology, which he found himself compelled to deal with in the interests of his philosophy of man and man's mind. The special value of this masterpiece today is that it is an exposition of organic evolution which is independent of the truth of any particular explanation or series of explanations of its factors. In 1894, when the late Lord Salisbury delivered his presidential address to the British Association, in which he criticized the idea of natural selection, Huxley took the opportunity to say that "if all the conceptions promulgated in the 'Origin of Species' which are pecul-

iarly Darwinian were swept away, the theory of the evolution of animals and plants would not be in the slightest degree shaken." A more recent historian observes that though the principles of evolution, as systematized by Spencer, received recognition only through the influence of the special doctrine of natural selection, they may yet survive that doctrine. Natural selection, or, in Spencer's own phrase, gladly adopted by Darwin, the "survival of the fittest," is invaluable in teaching us that survival is not at random, but depends upon superior fitness, but it tells us nothing as to the origin of the fittest; and that is why, today, such work as Spencer's is coming to be seen at its full value, for it goes deeper, and builds the positive facts of evolution upon the very nature of life.

The commonest accusation brought against evolutionists is that they are materialists. Spencer's definition of life may be quoted in evidence — by those who have read no further. Life is indeed manifested to us as the "continuous adjustment of internal to external relations," but the how and the why of the adjustment remain unanswered, since, as Bergson points out, life does not repeat the shape of its surroundings, but replies to them; and since, also, life is never content with adequate adaptation, but keeps on pushing towards other forms, of which some will be higher than any that have gone before. Let those, then, who would suppose Spencer's definition to be merely mechanical, and inadequate to express the mystery of life, be reminded of his own comments upon it. "It needs but to observe how simple forms of existence are in their ultimate nature incomprehensible, to see that this most complex form of existence is, in a sense, doubly incomprehensible . . . only the manifestations of life come within the range of our intelligence, while that which is manifested lies beyond it." This supposed materialist, speaking of life, says that its "phenomena are accessible to thought, but the implied noumenon (the reality of which phenomena or appearances are only the manifestations) is inaccessible."

Elsewhere reference has been made to one of Spencer's notable contributions to what may be called the mechanics of evolution. We have seen that all evolution has depended upon cell-division, for cell-division means the possibility of cell-variation, which is the principle which underlies all evolution.

The differences in cells as they divide involve different function and division of labor, so as to produce an organized

A YOUNG GORSE PLANT THAT HAS DEVELOPED PROTECTIVE PRICKLES WHEREBY IT IS ABLE TO THRIVE ON OPEN HEATHS

body such as ours; and if the new cells, instead of adhering, pass on to form new individuals, some of those may give rise to unprecedented forms of life. Hence the importance of Spencer's "law of limit of growth," which finds the key to cell-division and to the observed limit of size of individual cells throughout the living world in the fact that an enlarging cell increases its volume at a greater rate than its surface, by which it feeds and breathes, and must therefore divide, if the "push" of life is to be continuously maintained.

The real unit of life must be something smaller than the cell

Spencer accepted Lamarck's view of the inheritance of the effects of use and disuse, and in that one respect we now reject his contributions to the study of heredity. But in another respect we have confirmed him. For convenience' sake we call the cell the "unit of life," in order to emphasize the truth that the bodies of all living creatures are made up of cells. But we have already seen that, for a time at any rate, the divided portion of a cell will live. The real unit of life must therefore be something smaller than the cell. This we see clearly if we consider, above all, the case of a germ-cell, the bearer of the hereditary characters from parent to offspring. This cell is a unit in a true sense, but it is made up of smaller units, which are themselves alive. The cell is really the *anatomical unit*, the unit of structure. It is, of course, made up of vast numbers of chemical molecules, simple and complicated, which we may call chemical units. These molecules are not themselves alive. But intermediate between the cell and the molecules there must be units which are composed of many molecules, and which are *alive*. These discharge the functions of life, and to them Spencer gave the name of *physiological units* — a "magnificent all-sided conception," in the words of one of his most discerning critics, Grant Allen.

But though invisible they must be larger than mere chemical molecules

Since Spencer's day every biologist who has studied the cell has seen that he was right, and that there must be invisible living units in the cell, smaller than it is, but larger than mere chemical molecules. Weismann, Haeckel and many other biologists have introduced new names for the idea, but one and all are simply renaming what Spencer called physiological units. If we recall the facts of cell-division we shall see that the modern microscope goes a little way towards actually seeing what Spencer saw must exist. The division of the nuclear chromatin yields a series of individual bodies which we called chromosomes or color-bodies, and these, as we saw, split and yield halves which go to each of the daughter-nuclei. Each of these chromosomes is obviously a living unit, smaller than the cell. But even chromosomes may be seen to be composed in some cases of smaller units, and these are doubtless composed of still smaller ones, which, invisible by the most powerful microscope, are the real units of living substance.

The infinite divisibility and complexity of the smallest germ-cell

There is basis in this great idea of Spencer's for forming some kind of visual picture both of heredity and of development. The number of physiological units in, say, a germ-cell, or in the new cell formed by the union of two germ-cells, may be thousands; and if we endow them with variety of form and function, such as they must have, we begin to see the possibility of the transmission of numerous characters from parent to offspring, and the appearance of those characters in the course of the development of the offspring. When we think how tiny these germ-cells are, and yet how they somehow contain the physical basis of all those details of structure which we see in the fully developed individual, the problem before us at first seems hopeless of comprehension. Most of all is it so if we think of the cell as a simple thing, the "unit of life." It is unthinkably complex, crowded with smaller "physiological units," the possible number of which can be realized only if we appeal to the physicists and ask them to tell us about the size of atoms and molecules. Their answer is a staggering one, though the readers of another section of this work should not be unprepared for it. "The physicists report that the image of a *Great Eastern* filled with framework as intricate as that of the daintiest watch does not exaggerate the possibilities of molecular complexity in a spermatozoön (a male germ-cell), whose actual size may be less than the smallest dot on the watch's face."

THE TIRELESS ACTIVITY OF THE CELL

This microphotograph of the growing point of a pine-branch, enlarged some eighty thousand times, shows the tremendous activity that goes on in the cell-production that we call growth. The cells that form the mass of tissue at the tip of a branch are continually dividing up to form others. Some cells remain behind to form the vascular tissues of the stem, others are thrown off in layers to become leaves. The nuclei in the lower stem-forming cells are distinctly visible. Photo by J. J. Ward.

The nervous system developed from contact with the outer world

Plainly, therefore, there was nothing unreasonable in the suggestion that the physiological units in a germ-cell might number thousands, and the facts of heredity and development begin to become more intelligible. Lastly, on this point, it may be noted that the Mendelian study of heredity entirely confirms the theory of Spencer. Mendelism clearly points to the existence, within germ-cells, of numerous *somethings* which determine the future development of the individual. These things go sometimes into one germ-cell and sometimes into another, being distributed in an orderly way among the germ-cells in the process of their formation. They are called "Mendelian factors," and we see that the physical basis of these factors must correspond to those functional units of the living cell which Spencer was the first to recognize.

To one other fact of development does Spencer contribute. We saw his argument that touch is the mother-sense, and that the others are evolved from it. Thus the nervous system, which is the center of sensation, should be derivable, historically, from the *outside* of the body, next the external world. Yet we find the central nervous system in the inside of the body — inside, indeed, a complete case of bone, which, in its turn, is covered with muscles and skin. But if we trace the history of the individual we find an astonishing fact — that the entire nervous system, brain and spinal cord and all, is developed from the outermost layer of the embryo, and thus has the same origin as the skin. At a very early stage, a portion of the outer layer is turned inwards, becomes inclosed in the substance of the developing organism, and ultimately develops into the nervous system, the seat of intelligence. This adds force to the view that the intelligence was evolved by and for converse with the outer world, if we infer, from the history of the individual, that such has also been the history of the nervous system in the evolution of life.

What science says explaining the fall of the birth-rate with the rise of civilization

Yet another contribution of the apostle of evolution to our understanding of its processes must be mentioned, especially as it bears upon the problems discussed in other sections of this work. Spencer built the whole of his philosophy of evolution upon the doctrine of the conservation of energy, which he recognized to be as true of the energy displayed in living organisms as anywhere else. If, therefore, energy be expended exclusively upon the development of the individual, there will be none left for the purpose of reproduction. On the contrary, if the individual, directly it reaches maturity, spends all its energy upon reproduction, its individual life must be sacrificed. This, indeed, we see in the case of those organisms which subdivide for reproduction so that their individuality totally disappears.

From such considerations Herbert Spencer was led to frame a "law of multiplication," expressing what he called the "antagonism between individuation and genesis."

This antagonism was asserted by Herbert Spencer to be true of the whole of the living world, as, indeed, it must be if the law of the conservation of energy be valid, for one cannot eat one's cake and have it. But from this law it follows that, if the quality of individuals rises, if their maintenance and their development to maturity require much energy, expended for long periods, so much the less will be the quantity of energy which they have available for the purposes of reproduction or genesis. They must therefore produce fewer offspring, and thus offer the remarkable paradox, which today puzzles and outrages so many commentators, that, as life ascends and becomes more successful, the birth-rate falls. It has been falling since the dawn of life, on the whole just in proportion as life has ascended, simply because the superior development of individuals has ever involved the reduction in the number that life could afford to produce, unless it was to go bankrupt.

The problem of non-multiplication by the most highly developed

That this law, discovered by Spencer, is philosophically and practically true cannot be questioned. It is one of the cardinal facts of evolution, and can never be omitted from any attempt to explain the factors of evolution, such as we are all trying to make today. Spencer clearly shows that this law of the falling birth-rate, from the humblest to the highest forms of life, is beneficent and economical, for it reduces the proportion of death and birth to life, and it coincides with a steady reduction in the mortality of the immature, which seems and often is wasteful, though much less so than is often supposed, as we have shown elsewhere. This doctrine applies to man and woman as it does elsewhere, and most notable consequences may be deduced from it regarding the individual development of women, so long as "genesis" involves a vastly greater strain upon the female than upon the male organism. For it would appear that the highest and most exhausting development of the individual, without leaving any energy to spare for other purposes, may tend to produce, as the recent American evidence of the higher education of women suggests, a being who is admirable and complete in herself, but who fails to perpetuate her kind for the coming world. It will suffice thus to hint that the fundamental law of all life, enunciated by Spencer half a century ago, may have to be reckoned with by sociologists and eugenists for their own purposes no less than by the evolutionist for his.

Growth from within through the operation of a creative and eternal energy

Lastly, let us observe what evolution really means, according to Spencer, as contrasted with any process of manufacture. Evolution means internal development of dissimilar, definite products from something which is all similar and indefinite. Contrast, for instance, the solar system and the shadowy nebula or fire-mist from which it has evolved. Contrast the body of an adult organism with the undifferentiated, though marvelously potential, cell from which it has been evolved. Contrast a modern society with a primitive horde of human beings. Evolution is always, as the name implies, a process of unfolding from within.

Thus we contrast manufacture with evolution. If we wished to make a new society in some uninhabited country, we should have to import a certain number of traders and doctors, and factories and churches, and customs, and so, by putting together a sufficient number of the right things, we should make a society. So, when we manufacture a machine, we construct wheels and axles, and gear-boxes and levers and cranks, and what not. The machine is manufactured by putting all these together, by "assembling" its parts, as the engineers say.

But living art, living beings, the living universe, are not so manufactured by putting parts together. They grow from the mind of the artist, from the power of life, from the creative and eternal energy of Deity. Henri Bergson saw all of this, and states it as follows, the italics being his: "Mechanism holds that Nature has worked like a human being by bringing parts together, while a mere glance at the development of an embryo shows that life goes to work in a very different way. *Life does not proceed by the association and addition of elements, but by dissociation and division.*"

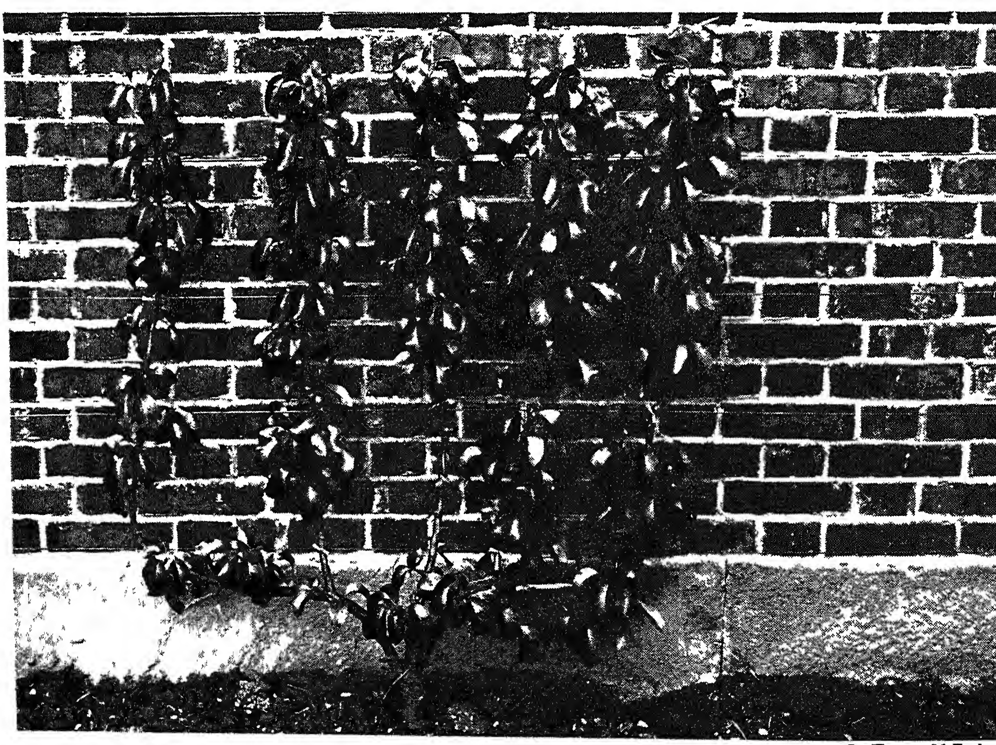
Can we not say that creative and eternal energy is divine?

That is why the future of life always overflows its present, and beggars our predictions. Evolution is a growth from within, an unfolding of potentialities which are inexhaustible, and to which we, ourselves but illustrations thereof, can put no limit. Such is the idea of organic evolution, as part of universal evolution, which we owe in its modern form to the great Englishman who thought that God must transcend our ideas of consciousness and will as these transcend mere mechanical motion, but who has not yet found a niche in Westminster Abbey.

Photos, Bureau of Plant Industry, USDA

These apples fell before harvest time from a tree that was not sprayed with plant-growth regulator.

Sprayed with plant-growth regulator, this fine tree retains its apples until they have ripened.



J. Horace McFarland

Far more fruit and much less wood growth are produced by the pruned pear tree that is shown above.

THE TREATMENT OF PLANTS

Dwarfing and Shaping Trees and Opening Them to the Sun, with Cross-Fertilization and Transplantation

SURGERY AND MEDICINE IN THE GARDEN

WE have now reached that stage in our consideration of the subject of plant life when it will be well to take stock of our ideas, because we are at what we may term the parting of the ways in our subject. That is to say, we are on the point of leaving behind the consideration of the general and fundamental principles upon which the science of plant life depends, and are about to turn our attention to the study of the more detailed processes which may be observed in individual species and families. These general principles must be mastered before anyone can hope to obtain an adequate conception of what plant life is and does.

But the modern student of such a subject, if he would wish to so utilize it as to widen his conception of life as a whole, must go even further than this. The contents and arrangement of these pages have been purposely designed to meet this end. Those who have read the earlier pages must have been struck with the great idea which the writers have endeavored to present — namely, that the universe is one in itself, and that the greatest thing in it is life. For the convenience of study and description, this great problem of life has been subdivided into Life, Animal Life and Plant Life; and the point that we are at present endeavoring to impress upon our readers is that, in order to appreciate any one of these aspects thoroughly, the other two must be equally studied. In each it was necessary to begin with general conceptions before passing to the study of detailed instances, and so in this section, which is devoted to plants, we now find ourselves in this position.

We endeavored to realize, in the first instance, that the soil itself, and all that it contains, was the foundation of our subject. So we studied its origin, its history, its composition, the food it contains, the bacteria that live and work in it, the marvelous and complex processes which these organisms carry out, the amazing potentiality of the soil, its preparation and cultivation, how these could be assisted by natural and artificial manures and, finally, the problems connected with seedtime, seasons and harvests.

All these are great questions, having fundamental principles behind them bearing upon plant life. Now, as we have said, we have come to the parting of the ways in our subject, and are about to devote our attention to more detailed topics.

Man, having entered into the heritage of the plant world, was not long before he ventured to endeavor to improve upon the natural conditions as he found them, by artificial measures derived from his own fertile brain. He observed that if plants be left to themselves some perish in the struggle for existence, because they cannot compete with the virility of those around them. In the absence of weeding and tillage, and so forth, none but the strongest could flourish, and they only at the expense of their weaker neighbors. But among these plants which so perish, or which would do so under such conditions, were a great many whose beauty of design and form and color, or whose value from the point of view of foodstuffs, made them eminently desirable to retain. Man, therefore, set his brains to work, and the result was — artificial cultivation.

To what perfection this has attained nowadays our following pages will to some slight extent show, especially as regards the processes which man has devised. These processes are not, however, restricted to the treatment of the soil in which the plant lives, but have been carried actually into the region of the treatment of individual plants themselves. In fact, there is at the present time in all modern agricultural lands a system of medicine and surgery in connection with plants as well as animals. We say medicine and surgery advisedly, because these artificial processes involve the use of both drugs and knife. The former are widely used as preventive measures in the case of threatened attacks upon plants by bacteria and other parasites. They are applied in the form of sprays and washes, and so forth, some of which we shall study later in connection with plant diseases. It is with the latter — the use of the knife as a way of altering natural conditions of growth — that we are at present concerned.

FRESH SHOOTS SENT OUT FROM THE ROOTS OF A TREE THAT HAS BEEN CUT DOWN

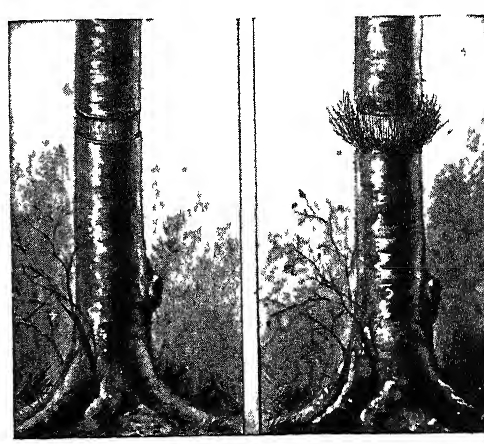
This subject of the surgery of plant life is an intensely interesting one, because it is not exactly on all-fours with that seen in connection with animals, which brings before us a difference in plant and animal constitutions which must be emphasized at the outset. It is a biological point of the greatest importance, one that those who are studying life in its various aspects should endeavor to grasp, and of which the significance must be realized.

In the case of any of the higher animals, when once they have attained their full growth or adult maturity, no new parts or organs are added to the body. That is the law of growth for the animal. It is a very strictly defined one. In any good species it is so definite that it can be stated in figures for the individuals comprising that species. Thus the anatomist, the physiologist or the comparative pathologist could tell us at once the average size and weight of the heart, the liver, the lungs, the kidneys, the spleen and so forth, for all higher mammals. He will also tell us that if any of these organs, or a limb, such as a forearm or a leg, be cut off *it will not grow again*. The possibility of transplanting, in adult species, one part of the body to another in higher animals is strictly limited. True, a certain amount of skin can be so transplanted, and this is an extremely useful proceeding in certain cases. But it is quite impossible to transplant a leg or an arm from one of the higher vertebrates to another. It will not grow. Not only that, but the removal of any considerable portion of animal tissue in a mammal is followed, at the best, by a process of healing which does not in any way replace that which was lost. Such second tissue is merely protective and not regenerative.

Standard Oil Co (N J)

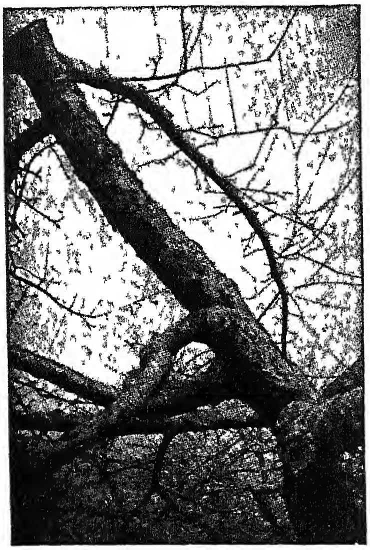
THESE TREES, IN THE AVENUE DENFORT ROCHEREAU, IN PARIS, ARE TRIMMED LIKE THIS EVERY THREE OR FOUR YEARS SO THAT THEY MAY BE KEPT UNIFORM IN SIZE AND SHAPE

In the plant world all this is different, and it is upon this difference that what we have termed the surgery of plant life depends. During a recent storm of exceptional violence the writer observed an ancient tree, perhaps a hundred years old, shattered and broken, leaving nothing but a stump To all appearances it was a total wreck, a mass of hopeless destruction. The thick foliage which had cast a welcome shade over the thoroughfare was drying up and dying, and already the boughs and branches were being sawed into convenient lengths for purposes of firewood. It was as if an animal had been blown to atoms by a cannon shot, leaving nothing but its head or its feet. Had it been such a creature there would have been nothing for it but a decent burial. But it was a plant, not an animal. The plant surgeon knew that, instead of the life of the old tree being destroyed, all that was necessary was to trim the broken wounds by the application of the saw, and to wait in patience until next spring, when — marvelous as it is to think of — fresh life would penetrate the wrecked and shattered trunk, and be evidenced in fresh green shoots In yet another year these would themselves give off lateral branches and in time they would show a glorious crown of foliage.

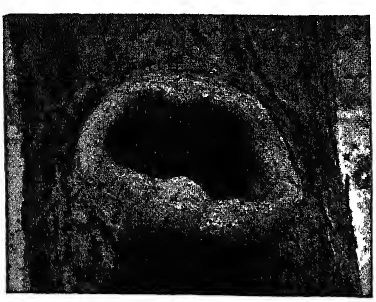


WILFUL INJURY TO A BEECH, AND THE NEXT YEAR'S EXUBERANCE OF SHOOTS BELOW IT

This simple illustration of an everyday occurrence will impress upon us the fact that there is hardly any limit to the operations which the plant surgeon may attempt without risking the life of his patient. He has learned this fact, and hence he hesitates not to cut and prune wherever experience has taught that it is advisable; and not only that, but he will venture to tear a plant — with all due gentleness — from its hold in the earth, and even to apply the knife to its very roots, replanting it in perhaps a different situation. Such is the remarkable tenacity with which plants hold on to that mystery of life which enables such radical things as these to be done.



HOW TO CUT UPRIGHT BRANCHES
In heading back upright branches the cut should be made just beyond an outward extending branch as shown in this picture



A NEGLECTED WOUND
Decay starting at this point has extended far down the trunk Large wounds like this should be well coated with paint

Doubtless it was the observation of some such fallen tree springing into new life — as described above — which led the primitive agriculturist to devise the various methods of pruning that have been in existence for a very long time. It would be observed that branches which were broken off, or twigs that were shed, were in due time replaced by others, and thus would arise a belief that surgical interference with the structure of parts of a tree might be pushed to almost extreme limits. The new growth that follows such amputations is developed by means of the buds in the stem which have been lying dormant. Upon their existence depends the whole success of the operations of pruning in all their phases.

Pollarding is another example of an analogous operation. Pollard trees are kept cut down to a particular altitude; and the result of this is that a copious and plentiful outgrowth takes place just below the level of the section. Examples are frequently seen in the case of willows Vines are sometimes treated in a similar manner, and so are a great variety of fruit trees. All operations of this particular kind have the same object in view — namely, to promote the growth of an increased number of more vigorous branches from the stem which is retained, or to increase the harvest of timber in the case of forestry, or fruits, as desired. In fact, by varying the position of the operation it is thus found possible to produce almost any kind of shape of tree desired. Hence the weird examples sometimes found in gardens in which the evergreens have been pruned to outline the shapes of birds and beasts.

It must not be supposed, however, that identical methods of pruning will produce the same results on all plants and all trees; indeed, this is very far from being the case. Different species of trees and shrubs have their own particular growth in connection with the dormant buds from which the new branches arise; and it is for this reason that experience has shown that it would be ridiculous to pollard an apple-tree, as is done to the willow, or to attempt to produce a thick undergrowth in a forest by means of pines.

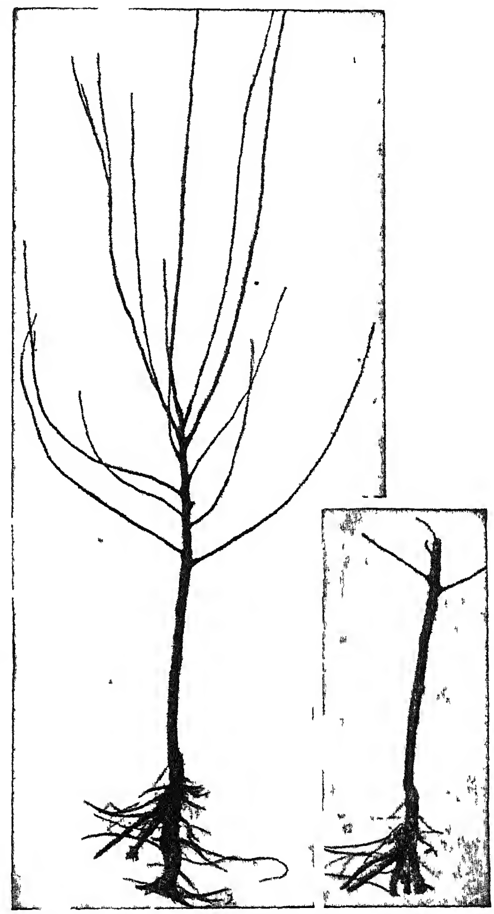
The natural habit of growth of the individual must be taken into account when the method of its pruning is considered. Climatic influences also have a bearing, an excellent example of which may be seen in the various modes of pruning in the vineyards of different countries. Thus that employed in Hungary differs from that on the Rhine, as does the latter from that in northern Italy, which, again, is quite distinct from the methods practised in southern Italy or the United States.

Of all these surgical interferences in the treatment of plants, pruning is the one to which we may pay most attention at this stage; and, since it is always well to be as concrete as possible, we may consider it in connection with the tree which will be found wherever these pages are read, and which will therefore offer familiar examples of what we say. That tree is the apple-tree. This fruit is of such immense commercial importance, is such a common article of diet, and has had, moreover, such immense attention paid to it in this very matter of various methods of propagation, that one could not select a better example for our purpose.

It would be a mistake, however, to think that there is unanimity among the recommendations of the various authorities as to regular pruning methods. On the contrary, there is a good deal of difference of opinion. That is partly because of the different conditions which obtain in various regions of the world, and also because of what we may term the "individuality" of trees. These factors have given different results to different experimenters, and hence the fruit-grower may have some difficulty in deciding upon his procedure. Trees which are growing rapidly and strongly must be treated upon different lines from those exhibiting a weaker tendency; and those which are obviously endeavoring to shoot straight upward will require treatment other than that which would be applied to growth tending laterally. Then, above all, the fruit-grower must have in his mind a picture of an ideal tree such as he wishes to produce, and upon this model his pruning operations.

In connection with the apple-tree, a great deal of experimental work on the subject has been done at the famous Storrs Agricultural Experiment Station in Connecticut. From these experiments we would deduce the following conclusions:

The difficulty of harvesting fruit from high-headed trees, as compared with low-headed trees, is about 25 per cent of the crop in favor of the latter, which are, more-



A TWO-YEAR-OLD NURSERY TREE BEFORE AND AFTER PRUNING

over, much more easily sprayed and more conveniently pruned and trimmed. In addition, other things being equal, the lower trees are less liable to injury from wind. For these reasons chiefly the present tendency is to prefer low-headed trees.

Then comes the question of the shape of the tree itself, and this is particularly concerned with the advocacy of the type of

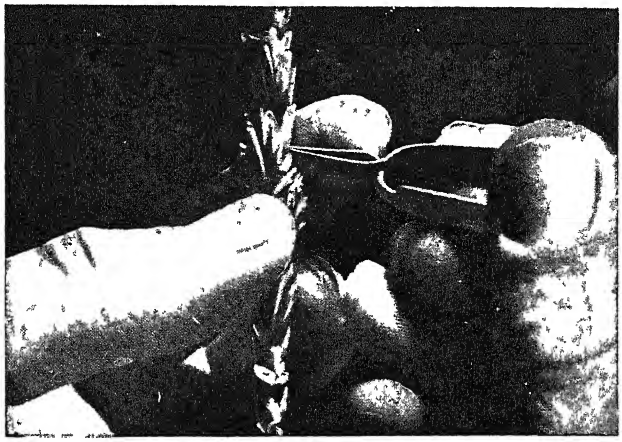
tree with *the open center*. The object of this method of pruning is, of course, to allow of the free access of sunshine into the middle of the tree, and hence to produce more fruit of a better color and richer flavor. But, after all, the greater part of the fruit is not borne in the center of the tree, but at its periphery, so that it would appear that the most important point is to develop to the utmost extent the surface of the tree which can be exposed to the light True, the opening of the center will improve such apples as there are in it, but probably it would be of still greater advantage to open the tree moderately on all sides.

No amount of description on a printed page can be made to explain clearly to a reader the various methods which may be adopted for the several stages of pruning. But our different illustrations will show at once the principles upon which a decision is made concerning the branches that are to be cut out and those that should remain. It will be seen that the object in view is to produce a tree with branches as evenly distributed as possible, leaving plenty of space between them for the admission of sunlight and free access of air. Generally, pruning should consist of "thinning out" of branches rather than "stubbing" back. In the latter, it is preferable to cut to a lateral branch. How much should be removed, experience only can teach, because the appearance of a tree during the winter when the leaves are off gives a very deceptive impression of the amount of its foliage, especially that carried by the smaller branches during the summer. It is for this reason that the most common error is the leaving of too much small wood. It is quite true that in so removing small branches the number of apples — or other fruit, as the case may be — may be somewhat reduced, but this numerical reduction may be compensated for by the improved size and quality of those which are ripened.

THREE FRUIT-BEARING LATERALS OF AN APPLE-TREE
The weight of the fruit is bearing down three lateral boughs and restricting the flow of the sap

When it is a question of determining which of two branches should be cut out and which left, it is better, as a rule, to retain the lower one. The two branches should be compared mentally as to their relative importance for fruit-bearing, spraying, gathering and other processes. Especially should all the unsightly branches which cross one another in the middle of the tree be cut out and, needless to say, any portions of dying or dead wood ruthlessly excised. In order to maintain an even shape it is necessary to prune back the rapidly growing young shoot at the extreme ends of the branches, and none of the sprouts which come up where the trunk enters the ground should be left. However, fruit trees should not be sheared unnecessarily and sometimes a watersprout may replace a broken branch.

The ultimate shape of the tree can be largely controlled by paying attention to the exact position and direction of the cut made by the operator. For instance, if it is desired that a branch should extend outward, the cut should be made at a point just beyond a bud, or another side branch which is already growing in the direction desired. Similarly, if the object is to induce a spreading branch to grow upward, this object may be attained by the cutting back to a bud or other branch already tending in that direction. In addition to these operations controlling the ultimate shape of the tree, cuts which are made close to side branches heal up much more satisfactorily than those at a distance. The cuts in trees should be made quite close and parallel to the branch from which the removed portion is springing. If it be made too far away from a bud or branch the portion left is apt to die or decay, forming a point of entrance for fungi, which may ultimately result in the hollowing out of the trunk that one so often sees in an old orchard. In order to promote the healing over of the cut surface, it is customary to treat the wound with gas tar or a coat of paint. As regards the special tools used by the operators for the different kinds of pruning, one need only say that they consist of a saw, some pruning-shears, or what is sometimes termed a "lopper," this last implement being used to cut back the topmost branches of the tree. The next point to consider is the time of the year at which pruning should be done. According to the season chosen, slightly different results are obtained: thus, if the pruning be done during the season when no growth is taking place, the result is the stimulation later of new growth of wood. On the other hand, pruning during the season in which wood is growing may induce increased fruitfulness. Hence it is that both summer pruning and winter pruning may be adopted for various purposes. A tree which has the habit of making too much wood and too little fruit may have this tendency checked by proper summer pruning. That is to say, the rapidly growing shoots are cut back at the height of the growing season.



A MODERN METHOD OF CROSSING WHEAT
An anther containing pollen is suspended from the end of the forceps

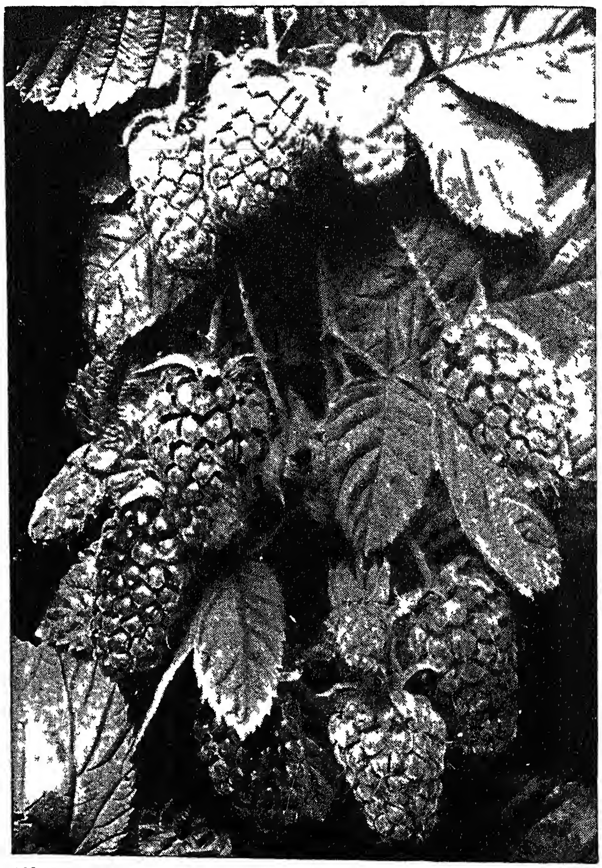
As regards the winter pruning, it is claimed by some that the early spring pruning heals up better, but, on the other hand, the fruit-grower has more time to spare in the late autumn and winter, and, as a matter of fact, usually does his pruning whenever the weather is favorable. More important, perhaps, is it to remember that it is better to do a certain amount of pruning every year than to allow the trees to grow in such a way that a heavy pruning is required at longer intervals. No hard and fast rules can be laid down for universal application, because no two orchards are precisely alike in their requirements. But the principles of procedure in all cases are the same — those which we have outlined.

The medicine and surgery of plant life are, however, by no means confined to the application of drugs for the prevention of infection and the use of the knife for the removal of dead portions or for the varied purposes of pruning. It goes much deeper into the mystery of life than any of these processes, because it is employed actually to produce types of plants themselves. In other words, the discoveries of plant physiology enable the plant doctor, so to speak, to interfere artificially at the actual moment of conception and to produce, within certain limits, almost any kind of plant.

This process is what is known as "hybridizing". Very many of its aspects are dealt with in other portions of our chapters on Life, Animal Life, and Plant Life, and other aspects of it will be treated of in this section later in connection with the detailed study of reproduction Some preliminary statements, however, may be made at this stage when we are thinking of the artificial interference with the normal life of plants which man can successfully attempt

The possibility of hybridizing, of course, depended upon the establishing of the fact that in the plant world, as well as in the animal, the separation of the male and female sexes is a widespread occurrence The significance of this evolution of sexes in animals has been argued in great detail and we may state here that it seems fairly obvious that the advantage of the separation of the sexes in plants must be connected with the process of cross-fertilization. By cross-fertilization we mean the transferring of the pollen-cells from one flower to the stigma of another flower which contains the female germ-cells in its ovary This may be done between plants of the same species, and also between plants of different species.

It is in the latter case that we have the process of hybridizing. By utilizing the facts which have been observed, man has been able to produce, in fact actually to create, new crops. One of our illustrations shows the actual process by which the operator is transferring in a small pair of forceps an anther containing pollen. In this case it is a wheat plant that is being artificially crossed. It was at one time thought, if the progeny of a cross turned out to be themselves fertile, this was sufficient to prove that the parents utilized were of the same species, whereas if the progeny were sterile the parents must have been of a different species This test, however, of the identity of species has had to be abandoned as the result of experiments in recent years, because quite a number of crosses have been made between plants of different genera without interfering with their fertility. Some very curious crosses have been experimentally produced, and some of these among plants which differed widely in appearance Thus the black currant and the gooseberry have been crossed, as have been the flowering currant and the gooseberry, and wheat and rye The first hybrid plant recorded was probably that of Fairchild's sweet-william, produced by a gardener of that name in 1719 by crossing a carnation and a sweet-william. Many other observers followed, performing numbers of experiments along similar lines, but it was not until Darwin published his great book on "Animals and Plants under Domestication" that the science



AN EXAMPLE OF NEW CREATION — THE LOGANBERRY, A CROSS BETWEEN THE RASPBERRY AND THE BLACKBERRY

The Davey Tree Expert Co

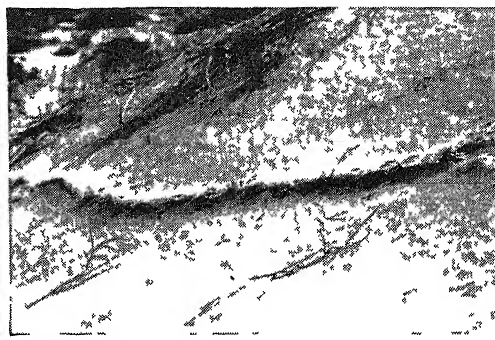
EXPERTS MOVING A LARGE DECIDUOUS TREE FOR TRANSPLANTING THE LARGE BALL OF EARTH THAT IS LEFT AROUND THE ROOTS IS CAREFULLY WRAPPED TO PREVENT DRYING OUT

of hybridizing was put upon a firm basis. An immense impetus has been given to it by the publication to the world of Mendel's experiments with peas, which will be fully dealt with elsewhere. Here our object is to emphasize from another point of view those things which the science of medicine and surgery as applied to plants is capable of performing. They could in this process of hybridizing actually determine the kind of living organism that is to be produced.

But even that is not all. Not only can the plant physician determine the direction in which the plant life is to grow; not only can he — having grown the plant — proceed to operate and amputate in every conceivable direction so as to produce just exactly what shape of plant he desires; he can do more than this, because he can uproot the whole organism from its nutritional basis and transplant it into an entirely new environment. Indeed, the operation of transplanting is now in agricultural work a routine procedure in the cultivation of many plants. By its means immense numbers of plants can be grown in a restricted area up to a certain size, and can then be pulled up and sent almost to any part of the world to be transplanted in new surroundings. And although this is easier to carry out in the case of small plants, such as cabbages, yet it can be performed, if great care be taken, with very much larger growths. Quite a number of cases are on record where extremely large trees have been carefully uprooted, taken a considerable distance, and replanted with perfect success. It seems, indeed, as if there were hardly any limit to the extent to which the plant surgeon may interfere with the normal life of his patient, provided ordinary care be taken.

AN UNDERGROUND HUNTER—THE MOLE

The mounds shown above were made by the species of mole called *Scapanus townsendi*, found in Pacific coastal areas of the United States



Above: *Scapanus townsendi* in the flesh. Below: the trade-mark of the common eastern mole—the surface pushed up by his underground burrowing

U. S Fish and Wildlife Service

Ridges and mounds made by moles. The sectional view in the foreground shows part of a somewhat deeper runway that connects with the mounds and also with a hunting path that lies farther underground.

THE INSECT-EATERS

One of the Great Groups of Animals which Maintain the Balance of Nature and Preserve the Food of Man

LOWLY BENEFACTORS OF THE WORLD

DEAN BUCKLAND (1784–1856), who was among the boldest explorers in the realm of diet, used to declare that, after eating his way through nearly the whole animal kingdom, his progress was stayed by the insects. A bluebottle fly was too much for even his tolerant palate It is fortunate for the human family that not all mammals are dominated by such prejudices, or there would be no order of insectivores, and in this case very little life would exist on land

For insects, if left unchecked, would speedily denude the earth of all the vegetable growth by which the life of the larger animals is supported It is the function of the insect-eating animals to help in diminishing this great menace Of course, there are other agencies working in the same direction The birds are perhaps most important in maintaining the balance of nature; countless kinds of ichneumon flies are notable aids, as are many carnivorous insects. But, no matter how numerous and varied are their allies in the war on insects, nothing can take away from the high importance of the insectivores Inestimable is their value as a scourge of ground-haunting insects which, in perfect form or larval, prey upon crops; and the significance of the tree-climbing insectivore's contribution to the weal of the world is scarcely less evident.

Mighty as man seems, his existence is at the mercy of the insects; and the insect-eating birds and animals are among the most powerful of the bodyguard that maintains law and order for him It would matter very little to the insectivores if the human family were blotted out But the case would be very different for man if the insectivores were suddenly exterminated Every time that a shrew crunches the larva of some plant-destroying insect, a work of great advantage to man is performed. The achievement of the individual may seem small, but the aggregate effect is enormous. And these animal allies of ours, who flee from us as from the most terrific of ogres, and yet work almost continuously for our physical salvation, are among the most humble of quadrupeds With the marsupials and the egg-laying animals, they are the most primitive of mammals.

Life has flowed past them in an ever-widening stream, developing into new forms, waxing great and strong, but leaving them practically unchanged in the structure and habits which they acquired when all the world was comparatively young.

The tiniest mammal on earth is a shrew, but it represents a more ancient line than that of the lordly lion or the giant bear. For the insectivores were kin to the ancestors of the type from which all the carnivores rose. They lead on to the bats, winged insectivores, though bats are placed, of course, in an order of their own. The insectivores proper remain a distinct and peculiar group While externally resembled by some other mammals, they are wholly distinct in anatomy, and preserve for us the mold in which nature fashioned some of her earliest serious attempts at a mammalian type of life. It may be of service to note here that, because an animal occasionally eats insects, it is not necessarily an insectivore

The true insectivore is a mammal distinguished by the peculiar character of its teeth. None of the teeth has the flattened grinding surface common to the molar teeth of the majority of animals, nor are the teeth of the insectivore so shaped as to work with the shear-like action characteristic of the carnivore's. The insectivore's teeth are furnished with sharp tubercles, enabling the animal readily to seize, hold, and pierce the body of insect, slug or worm. In the structure of the insectivore there are anatomical traits readily distinguished by the man of science, but one external character strikes even the ordinary observer, and that is the long narrow, mobile muzzle possessed by nearly all members of the order.

How weaker animals seek the line of least resistance under keen competition

It is an immutable natural law that lower orders shall yield place to higher. Yet the insect-eaters are found wherever there is a suitable food supply, except in Australia, where their place is taken by marsupials. How, then, are we to reconcile this wide distribution of the insectivores with the above-mentioned law? That law and the prosperity of the insectivores are not inconsistent. These lowly animals have not yielded up their lives, but they have yielded up their places to stronger, more intelligent, better-organized animals. They have sought life along the path of least resistance. In continental islands where hungry carnivores have not had to be faced, the struggle for existence has not been unduly acute.

Under less favorable conditions, however, the insectivores have adapted themselves to circumstances in special ways. Some of them have taken to the water, some have become tree-dwellers, some burrow underground; some, like the hedgehog, have put on armor, while the cobego has developed the best natural parachute in existence, and has advanced nearer to true flight than any animal, after the bats. The latter, as we have seen, rose from the insectivores, but not from any type now living; the connecting links were snapped in ancient days.

A too easy life that has led the cobego to poor development

The insectivores have very small brains, of the lowest quality, yet, apart from their economic value, they are not to be despised. A group of animals, first among the mammals evolved, which has kept itself alive and efficient through all the fierce conflicts of time, and still well holds its own in the hard struggle for existence, deserves very special consideration. It is an order of about 230 species; and when we find it comprising "flying" animals, swimming animals, mining and armored animals, we cannot complain of lack of variety or interest.

The cobego's acquaintance we made in an earlier chapter, so we may dismiss it here with the reminder that though the best authorities now rank it with the true insectivores, there was for many years a tendency to place it in an order by itself. In the immature condition of its young at birth, it has affinities with the marsupials, but the wonder is that it never became a bat. A very slight process of evolution might have converted it into a flying fox, for, like those great bats, it appreciates a vegetable diet. Is it not strange to find a vegetable-eating insectivore? By what steps this animal was led to a life in the trees and to a diet consisting of leaves, with insects as quite an unimportant addition, it is impossible now to trace, but it looks as though the cobego has run into a blind alley of existence, and found no way out to better things. It does marvelously well with its parachute, and, content with that instrument, it has developed only an insignificant brain.

An animal that once had good sight but is giving it up as unnecessary

"As blind as a bat" is a common expression among people who do not realize that the bat has really excellent sight. "As blind as a mole" is a saying which incurs the censure of the countryman who happens to have seen the eyes of this denizen of the underways of the world. But if the mole is not yet blind, it is rapidly faling into that lamentable condition.

In the struggle for existence, this animal has been forced to burrow for a home and living. We cannot tell, of course, how long its underground habit has prevailed, but the period must have been considerable. For the time is approaching when the eye of the mole will be as functionless as the pineal eye of man himself. So degenerate has the instrument of vision become in the burrowing mole that, when the animal is skinned, the atrophied organ comes off with the hide. This condition has been brought about, it is surmised, not through any injurious effect of mining, but through the mole having, like the fish of unsunned caves, learned to depend upon smell and touch rather than on vision and a thumb of rare strength. It should, however, be noted that though the term "thumb" is employed, this digit cannot be opposed as can the thumb of a Primate. Practically all the insectivores have five fingers to each fore limb, but none has the thumb opposable. The fur of the mole is ideally adapted to life in earthy tunnels. The hairs are set vertically, and turn in any direction, so that no soil can defile the animal's wonderful coat. Perhaps the lot of the mole might be happier were his coat not so impervious to soil, for he is infested, like the hedgehog, with fleas and mites. Poultry take dust baths to rid themselves of parasites, but the mole, living in the soil, does not find the remedy efficacious.

THE PIGMY SHREW

The pigmy shrew (on the left) is the tiniest of mammals

THE COMMON SHREW

The common shrew is larger, though only $2\frac{3}{4}$ inches in length

Both animals, though mouse-like in appearance, are purely insectivorous.

This is a remarkable example of evolution in progress. In the embryo the eye of the mole is large; in the young mole it is larger than in the adult. The older the mole grows the smaller becomes its power of sight, until in the adult animal it is doubtful if the eye is more than sensitive to light. All this is extremely curious, seeing that the mole does not, as is commonly supposed, live entirely underground, but comes out at night, and sometimes by day, in pursuit of food.

But it is as a tunneler that the mole is chiefly interesting. For this work it is especially well adapted. Its forefoot is among the finest of natural excavating implements, being equipped with four fingers

Moles breed once a year, and the female gives birth to from two to seven young. Formerly it was believed that the males greatly exceeded the females in number, a mistake due to the fact that except at certain seasons there is a striking superficial resemblance between the two sexes. Males and females are now shown to be about equal in numbers. It would be serious for the underworld were the case otherwise, for even with the sexes equally divided battles between the males for the favors of the other sex remain fierce and deadly. Four or five males may battle for the possession of a single female, due to the fact that moles do not mate for life as do many of the higher mammals.

The fortresses of the European mole and the passages leading to them have long been famous as examples of animal architecture. The American moles are less elaborate in making their nests. An observer in England calculated that the work done by a mole in a single night in soil upon which rain had recently fallen was such that, in order to perform its equivalent, a man would have to excavate in a single night a tunnel thirty-seven miles long, and of sufficient size easily to admit the passage of his body.

The European mole's so-called "fortress" is really the chamber in which it makes its nest. The nest, however, is not used as a nursery. The female makes a smaller fortress for the reception of her young; and it is not known whether she and the male share the same nesting cavity earlier. In making his tunnels the mole excavates with his forepaws, and thrusts the loose earth to the surface with his nose and the top of his head. Tunnels are frequently carried round the fortress, and may lead to an exit or entrance at some distance from the mound, while others are mere blind alleys. Not all the twistings and burrowings form part of a settled plan; the mole seems at times to excavate merely from habit, just as the prairie dog digs holes unnecessarily.

The animal that is hardest worked because the most hungry and thirsty

On the other hand, many of the passages which have been examined and declared useless may have been galleries dug in search of water. No creature is more intolerant of thirst than the mole. He must drink and eat repeatedly; it is said that he cannot endure hunger for longer than three hours at a stretch. It is his incessant hunting for food which makes him a nuisance in gardens and cultivated lands. He consumes an enormous number of harmful grubs and larvæ, but, where he has undermined, field mice can follow, to get at seed and damage crops.

The mole family extends far and wide. A strange member of the clan is the desman, which haunts the banks of rivers and lakes in southeastern Russia. With its long, trunk-like snout, its curiously flattened tail, and strong musky odor, the desman — or muskrat, as it is sometimes wrongly called — is almost entirely aquatic, feeding on leeches and water insects, and rooting them out from weeds and mud with its muscular, mobile proboscis. Although its feet are webbed, it is a capital miner. The tunnel where it rests and brings forth its young runs as much as twenty feet into the banks of the stream in which it swims.

North America has three well-marked species of moles: the common or naked-tailed, which is similar in appearance and habits to the European mole; the Brewer's mole, an animal of like habits and form except that its tail is hairy, found further north than the common mole; and the star-nosed mole, which has a fringe of fleshy tentacles about its snout, and is much more aquatic in its habits. The American moles do not make the elaborate fortresses of their European cousins but they are just as active in their tunneling, which brings them into disfavor about lawns and gardens, where their hills disfigure the velvet grass and their burrows make runways for the destructive mice. Several types of traps are on the market for destroying moles but it is better to discourage them by continued rolling of the lawn than to kill them, for their food habits are very beneficial.

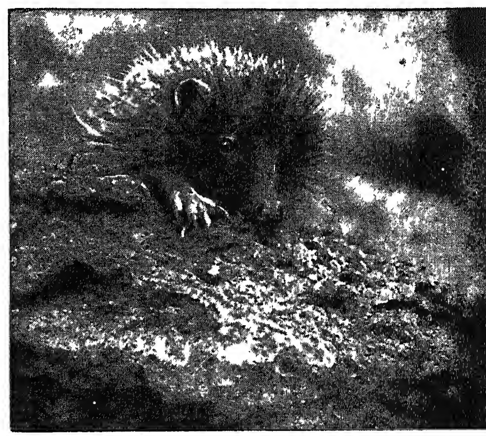
Between moles and shrews there is an interesting link in the shrew-mole, of which there are two known species, found respectively in Japan and America. The American species, more commonly called short-tailed shrew, is slightly smaller than a meadow mouse and is abundant throughout eastern North America about fields and woods. It is a bloodthirsty little beast and often attacks and devours the larger meadow mice, which undoubtedly form a large part of its diet. It lives on the surface of the ground and also in burrows, where it has its young, in spite of the fact that its feet are mouse-like and ill-adapted to burrowing. Its fur is dense and mole-like and of the same iron-gray color so that, among the undiscriminating, it passes for a small mole.

An ancient type of animal that persists through passive resistance

The hedgehog is the king of European insectivores. No hedgehogs exist in North America, for the animal often miscalled so is the porcupine. The hedgehog is one of the most ancient of existing mammals, very little altered today from the hedgehogs of millions of years ago. It is doubtful whether his mail of prickly spines was first evolved as armor; but as so many animals have adopted protective devices of this sort, we cannot be wrong in assuming that defense, and not adornment, was the purpose of the urchin's formidable great-coat.

Another crime laid to his charge is that of sucking the milk of cows. As the udder of a cow is highly sensitive, we have only to calculate what would be the effect of contact with the intensely sharp prickles of the hedgehog to see how much truth there is in this wild allegation. That the hedgehog likes milk is undoubtedly true, but he likes minced beef, too, and cooked vegetables, and soaked bread. Surely he is not on that account to be charged with robbing the butcher, the gardener and the baker!

The female hedgehog gives birth to four, five, even six young, and, her first litter being born in May or June, a second family may appear in October. The young are



THE EUROPEAN HEDGEHOG, WHICH LOOKS LIKE A PORCUPINE BUT IS IN NO WAY RELATED

The European hedgehog is one of the oldest of insectivores It has the meanest of brains, but its prickles, and the power to curl up in face of danger, have kept it alive where more highly organized animals have become extinct.

born blind, naked, and smooth, and their power to curl themselves up does not appear until the spines begin to develop and harden. A nest of leaves or the root of a tree, or the shelter of some hidden clump of soil or turf, suffices for a home. At least three generations of hedgehogs have been known to sleep beneath the floor of a summer-house in a certain garden.

The study of this family throws interesting sidelights on the struggle for existence which even these well-favored animals undergo. In addition to the insect resources of a garden of three acres or so, they find an additional food supply in the thousands of young frogs reared every spring within the boundaries of their home.

While almost all of the armored animals are now extinct, the hedgehog still flourishes abroad. He has never been driven underground, or to the water, or to the trees. His prickles, and his ability to curl himself into a ball of spikes, added to his faculty of going to sleep for the winter, have kept him safe and prosperous. His diet is chiefly insectivorous, but he will eat snakes and frogs, mice and young moles, and, it is said, young birds and eggs. His attacks upon the nests of birds have been hotly debated. Undoubtedly the hedgehog has been found devouring the eggs of ground-nesting birds, but it has not been proved that he himself broke the eggs. His apologists aver that a rat must have been before him to shatter the shells.

All that they have to do is to eat and drink and be merry. There are only two pitfalls in the garden, yet both have almost proved the undoing of the hedgehogs. One is a miniature lake, which is more easily entered than left. Though there is plenty of water elsewhere for drinking purposes in the garden, a hedgehog once sought to quench its thirst in the water of the lake, blundered in and was almost at its last gasp when it finally was rescued.

The second pitfall is supplied by a steep drop in the ground at one place in the vicinity of the fence that encircles the garden. This results in a penned-in area about a foot wide and many yards in length. Hedgehogs, some of them more than half

N. Y. Zoological Society

The elephant shrew (jumping shrew) lives in Africa. Note the trunklike extension of the snout.

grown, blunder into this "trap" and cannot get out. On one occasion a little mound of stones was built in order to enable two little trapped animals to climb up to the higher ground. A couple of days later, the two were still imprisoned. In spite of their exceedingly sharp claws they had apparently been unable to scale the "wall" that enclosed them; nor had they availed themselves of the bridge provided by the mound of stones.

The nearest relative of the hedgehog is a rat-like animal called the gymnura, or rat shrew. The latter name describes the external characteristics of this animal; but its teeth and its internal structure show that it is closely allied to the hedgehog. The gymnura is found in Burma, the Malay region, the Philippines and parts of China. There are several species, some as big as good-sized rats, others as small as mice. All are purely insectivorous. The discovery of fossil remains of an extinct genus of gymnura in France has been cited as evidence of the similarity between the fauna of Europe in prehistoric times and that of the present-day Malay Archipelago.

The shrews are widely distributed

The most numerous and widely distributed of all the insectivores are the shrews. The common shrew, or shrew mouse, found in Europe, Asia and North America, is about the size of a mouse and somewhat resembles that animal, particularly in the shape of its body, feet and tail; but it is distinguished from the mouse by its muzzle, which projects far beyond the lip. The common shrew feeds upon insects and their larvae, and inhabits dry places, making a nest of various kinds of leaves and grasses. The young, numbering from five to seven, are born in the spring. Common shrews are very voracious; they sometimes kill and devour one another.

The pigmy shrew is even smaller than the common shrew. Rarely more than three inches in length, this tiny animal is the smallest mammal of the North American continent.

The short-tailed, or mole, shrew is the best-known species in the eastern United States. It is about four inches long, with a hairy tail measuring one inch. It remains quite active in the winter; it is sometimes found burrowing in the snow. At this season of the year it feeds largely on beechnuts as well as chrysalids and larvae.

The tupaias, or tree shrews, are widely distributed in the countries of the Orient. They closely resemble squirrels and are sometimes mistaken for those animals. But the head, with its elongated muzzle, is typical of the insectivores, and the character of the teeth is unmistakable. Though arboreal animals, the tupaias descend to the ground in search of prey, and occasionally they even venture into human dwellings.

The jumping shrews, also called elephant shrews because of the trunklike extension of the snout, are the African representatives of the tupaias. They are ground animals and move by leaps, after the fashion of the kangaroo. The jumping shrews are entirely restricted to Africa. There are many species of these interesting animals. Some haunt the thick undergrowth; others dwell in stony wastes, where clefts and crannies in the rocks offer a secure haven during the dreaded hours of daylight.

China has an aquatic shrew that is more highly specialized than any of its relatives — the web-footed shrew. The soles of its feet are provided with disclike pads; these enable the animal to grip securely the surface of smooth stones and rock as it seeks its food in a river bed.

The musk shrew— the bane of insect pests

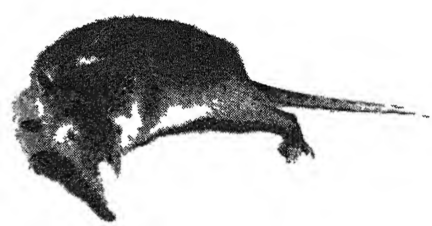
The musk shrew of India is remarkable for the strong, musky odor that emanates from glands situated on the sides of the body. Though it leaves an offensive musky trail, it is generally tolerated in the houses that it enters, because it feeds greedily on cockroaches and other insect pests.

The otter shrew of West Africa finds a place among the insectivores because of the insectivorous characteristic of its teeth. The muzzle is broad, not pointed, after the fashion of other insectivores; and this expert swimmer's habits — particularly its skill in catching fish — decidedly suggest the otter rather than the shrew.

The tenrecs and solenodons are closely related

Among the most fascinating of the insect-eaters are the tenrecs and the solenodons, which are closely related. The former are natives of Madagascar, the latter of the West Indies. The existence of these closely allied animals in such widely separated areas points to ancient land connections that have vanished under the seas.

The great tenrec is the most fearsome beast of the tenrec group. Tailless, it attains a length of sixteen inches and considerable girth; it possesses formidable teeth and it can inflict a serious bite. Its diet consists almost exclusively of earthworms; it hunts this prey only during the hours of night. To defend itself against its enemies, the tenrec has developed a formidable coat of armor, consisting of bristles and spines. This animal hibernates like the European hedgehog and it lives in burrows, which it excavates by means of its strong claws. Unlike the hedgehog, however, the great tenrec does not roll itself up into a ball-like form for defense.



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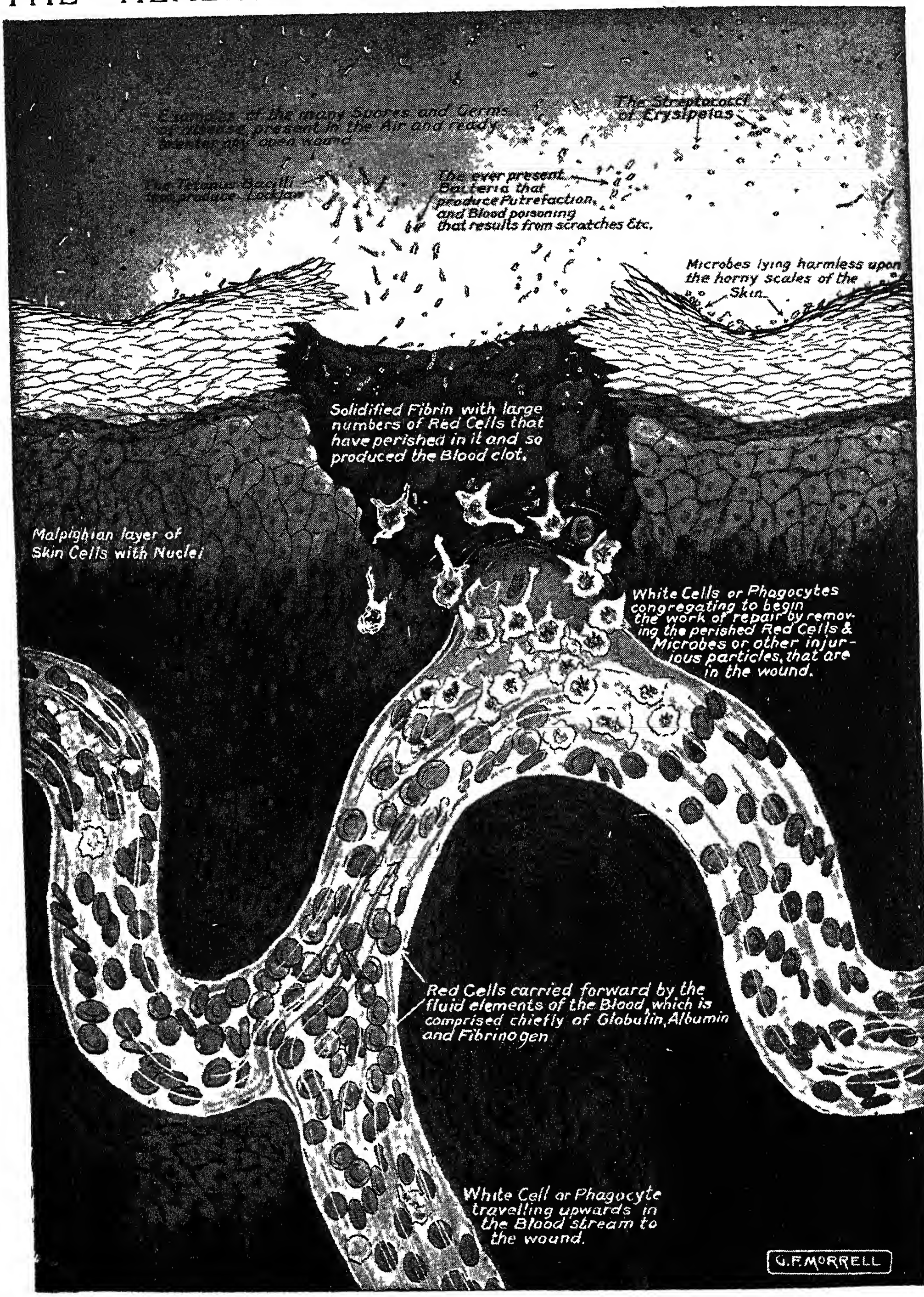
This little solenodon is an inhabitant of Haiti.

One species of tenrec has become aquatic. Another, the rice tenrec, carries its search for insects beneath the roots of growing rice to such lengths as to become a serious pest; more so, even, than the insect pests upon which it feeds. Tenrecs rank among the most prolific of all mammals; as many as twenty-one at one birth have been recorded. The flesh of these animals, especially before they hibernate, is highly esteemed by the natives of Madagascar.

The solenodons, found only in Haiti and Cuba, have long snouts and tails and large ears. The body of the solenodon is hairy; by way of contrast, the tail is naked.

We shall end our account of the insectivores with the animal known as the golden mole. It is to be found in eastern, southern and central Africa. This animal is more nearly related in structure to the tenrec than to the mole; still, in its habits of burrowing and tunneling it is clearly molelike. The ears of the animal are tiny; its eyes are buried beneath the skin. The coat has a metallic luster; it is this feature that gives the creature its name.

THE HEALING POWERS OF THE BLOOD



THE SENTINELS OF THE BLOOD HEALING A TINY WOUND AND DESTROYING THE INVADING MICROBES

This picture-diagram represents a greatly enlarged section of the skin, about one-sixtieth of an inch thick, with a tiny scratch sufficient only to tear open one minute capillary. On the one hand are shown the dangers from various forms of septic bacteria ever present in the air, and in contrast the marvelous provision of the blood and its many elements to protect the body by destroying intruders and allow the healing of the wound to proceed. Thrombin forming in the blood stops the bleeding by transforming the element fibrinogen into the solid fibrin of the blood-clot. For the sake of clearness the capillary and the red and white blood-cells within it are drawn larger in proportion than the tissues of the skin.

THE EVER PULSING STREAM OF LIFE

Living Blood always Circulating and Constantly Transformed
Carries the Body's Supplies and Repairs its Defenses

MAN'S BLOOD AS PERSONAL AS HIS FACE

THE body of man, like that of most animals, is provided with a complicated mechanism, of pump and tubes and nerves, for the circulation of a fluid called the blood. If the circulation ceases for more than a few seconds, we die. Thus, though there is no real meaning in the familiar phrase that "The blood is the life," the blood is necessary to life, and, further, its continuous motion is necessary to life. We may add that the blood is itself alive. Though it is fluid, and not a definitely fixed tissue, such as muscle or brain tissue, yet it comprises living cells as they do, and in quite as high a proportion to the rest of its composition. Its living cells do not enter into any mutual relation, and are not fixed, but we must call the blood a tissue; for it is at least as crammed with life as any tissue or organ of the body, and we should beware of being deceived by its fluidity. The blood can become a solid at any time, and is never more valuable and more alive than when it does so at the proper time and place. A portion of solid or clotted blood, actively engaged in reparative and constructive work — a tissue-maker, indeed — cannot possibly be denied the title of a living tissue which we grant to brain, or gland, or muscle.

There is a marked contrast in this respect between blood and such a fluid as milk, which is manufactured from the blood. The fluidity of both is deceptive, and only for convenience. Each can readily be solidified, and in that form gives us a much better idea of what it really is than when it is in the fluid state. We then realize that each contains a quantity of solids dissolved in water, which is true of all tissues. But though milk contains globules of fat it contains no living cells; and solidified or clotted milk cannot be called a living tissue, nor liquid milk a "vital fluid," as is too commonly done. Clotted blood, on the other hand, such as binds and repairs a wound, is a living tissue, if anything is; and liquid blood is a "vital fluid," in the fullest sense of the words, so long as we do not mean that the fluid part of the blood, in which its cells swim, is itself alive.

We cannot contemplate the circulation without guessing that the fluid which requires to be unceasingly moved on is so moved in order to undergo changes. Evidently something must happen to it. If for instance, every red blood-cell must pass through the lungs, say once a minute, it must either give or get something there, and be thus different according to whether we examine it in a pulmonary artery or a pulmonary vein. This general assumption about the circulation of the blood is proved by the simple observation that the blood in an artery and the blood in a vein differ in color. So marked and important is the difference that we speak of arterial blood and venous blood, the former being bright and red in color, while the latter is duller and of a red which, in the vessels, appears all but blue. We observe the color of venous blood in the face of anyone whose venous circulation is being obstructed by great cold or heart-disease or fury, or even a tight collar. Plainly, therefore, there is some radical distinction between arterial and venous blood and we cannot describe "the blood" as if it were a single, constant fluid

What we should see could we examine the blood on its way to and from the heart

If we had the opportunity of examining the blood in the pulmonary artery going to the lung, and in a pulmonary vein returning from the lung, we should further discover the notable fact that these vessels are exceptions to our rule. They are, respectively, artery and vein, beyond a doubt, because of their structure, and because the one leads from and the other to the heart. But we find that the pulmonary artery invariably contains venous blood, as we have agreed to call it, and the pulmonary veins contain arterial blood. If we remember the course of the circulation we see that this must be so, for the blood in the pulmonary artery is that which, a second before, entered the right auricle from *veins*, and is thus still venous, while that in the pulmonary veins will in a second be passing through the left auricle and ventricle into the prime artery called the aorta. Thus the definition of the two kinds of blood as arterial and venous is really accurate only in reference to the arteries and veins of the greater or systemic circulation; in the lesser or pulmonary circulation the facts are reversed. And the evident meaning of this must be that, in flowing through the capillaries of the body generally, arterial blood becomes venous, bright becomes dark, and, in flowing through the capillaries of the lungs, venous blood becomes arterial, dark becomes bright.

This is only the most evident and familiar illustration of the general truth that the blood is constantly altering in composition and quality as it passes through any capillaries anywhere, in consequence, evidently, of that all-essential leakage, in both directions, for which capillaries and the circulation of the blood exist.

The changes that take place in the blood while it is passing through the tissues

The blood that enters the liver, for instance, is a different fluid from that which leaves it. Not only is the blood that leaves the liver hotter, but it has been deprived of various constituents, and has acquired others; while even the number and quality of its red cells are altered. Again, the composition of the blood returning from the bowel after a meal is notably different from that of blood returning from the same capillaries before a meal; and the proportion of white cells in the blood after leaving the spleen and various other parts of the body must be greater than before; while young red cells, as we have already seen, will be more abundant in the capillaries leaving red bone-marrow than in those entering it. Thus the blood is not only a living tissue, from one point of view, its fluidity and movement notwithstanding, but it is also the great medium of exchange of the body, and its composition is modifiable, and, indeed, in many respects *must* be modified, from moment to moment, as regards every fluid constituent, and the number, kind and age of its living cells.

Yet, on the whole, the blood has constant properties; and nothing is more characteristic of it than its unfailing resource in keeping them constant. Its proportion of water, and of each and many salts, its specific gravity and temperature, the number and kind of its cells — all these remain, on the whole, amazingly constant in all vicissitudes. The great changes from arterial to venous blood and back again are rhythmical; the changes due to meals are transitory; those due to addition of new cells to replace old ones are only local, and do not permanently affect the general composition of the blood.

The blood the most mutable and unstable fluid in the world

Normally, therefore, we can describe certain very constant facts of a typical drop of blood; and this we may proceed to do if we remember, from the first, that, with all its constancy, this is also the most mutable and unstable and sensitive fluid in the world, and must be so if it is to live and serve the life of the body.

The cells of the blood are of two kinds, red and white. Further subdivision is possible, but this is the great and obvious difference, and no one can hesitate to describe any blood-cell as belonging to the one or to the other class. The red cells are without a nucleus, unlike the white

ones, but even the occasional presence of nucleated red cells in the blood can cause no confusion, for their destiny, color and category are obvious. The red cells are formed in the red marrow of the bones. When formed, by the cell division which is the same here as elsewhere, of course they have nuclei, like every other cell in the body at some stage or other.

How the blood alters itself to meet any new demand made on it

But as these cells are highly specialized for functions which require no nucleus, and as, indeed, the nucleus would take up room which is required for the packing of other things, it disappears at once, so that nucleated red cells are never found in normal adult blood. But if the blood be undergoing serious loss or damage of its red cells, as often occurs by accident or disease, we shall at once find nucleated red cells in it, showing how promptly and with what haste the body seeks to right the composition of its blood.

The red cells, when studied singly, are found to be yellow rather than red, but their enormous concentration produces the effect of red. The color is due to the one constituent for which the cells exist. Otherwise they have no powers or duties. They are circular, bi-concave discs, with an invisible elastic envelope, no internal structure, no trace of anything like their young nucleus and no power of movement. We cannot call them dead, but they are very little alive. The disappearance of the nucleus proves that; and there is no sign of any capacity for response or spontaneous action, much less reproduction, in red blood-cells. In all these respects their simple, passive, mechanical nature contrasts them sharply with the white cells. They exist simply in order to carry the red — or yellow — coloring matter, which is called hæmoglobin.

The most complex substance known to chemistry manufactured for the blood

The adult red cell is thus simply a porter, nothing more. But in its youth, and especially in its origin, it is far more, for the manufacture of the hæmoglobin is a great chemical feat; and when the new red cell is made, its hæmoglobin is made also. This substance is the most complex known to chemistry. It is a compound of many elements, and is built up by the association of many lesser compounds, into which it can easily be split. It is estimated that the molecule of hæmoglobin — the smallest quantity of it that can exist as such — must contain not less than a thousand atoms, and this molecule is not only the most complex, but one of the largest that chemistry knows. We should not underestimate the chemical skill, thus proved to be transcendent, of the cells in the red bone-marrow where hæmoglobin is made.

"The color of life" is due to this compound. It colors the blood, and supplies the material for color in many other fluids and tissues of the body. As we might guess, from our knowledge of the chemistry of iron and its compounds, hæmoglobin contains this metal; it is, indeed, "a compound of iron," apparently containing one atom of iron in each of its enormous and many-atomed molecules. But though the iron constitutes, perhaps, less than one-thousandth part of hæmoglobin, it is essential not only for its color, but for its existence, and therefore for the body's existence.

Curious parallels between the fluids circulating in man and in plants

We can further study the chemistry of hæmoglobin in blood that has been shed in the tissues or elsewhere — for instance in a "black eye." We find that this huge molecule breaks up into two parts called hæmatin and globin, the former containing the iron and being crystalline, while the latter belongs rather to the group of the albumins or proteins. Numerous further changes are possible, with variety of color, such as we see in a black eye when it turns green and yellow. But the chemistry of this all but unparalleled compound is a matter for the expert, beyond such a point as this.

One parallel it has — the chlorophyll or green substance found in the leaves and other parts of plants. This compound is

also colored, very complicated in structure, and must always contain iron. In the absence of iron, as food for plant or any creature that has red blood, such as man, these compounds cannot be formed, and the life must fail. Chlorophyll and hæmoglobin are equally widespread in the plant and animal world, above a certain humble level in each case, respectively. Each has an all-important function concerned with oxygen, the chlorophyll of the plant being the means of taking carbon from carbonic acid by separating it from the oxygen in that compound, and thus leading to the formation of carbonaceous foods for man and other creatures like him to burn and live by. This they do by combining them again with oxygen, which hæmoglobin carries from their lungs to their tissues.

An old name given by the Greeks that accidentally conveyed scientific truths

Thus, in a sense, and considering life as a whole, chlorophyll and hæmoglobin are equal and opposite in their action; and the parallel is completed by the recent chemical study of chlorophyll, which has brought out its remarkable chemical similarity to hæmoglobin.

These large considerations, though so general, tell us what happens in the body of man. We say that the red blood-cells are simply the mechanical conveyers of hæmoglobin, but we must go on to note that this hæmoglobin becomes changed as they carry it. The change appears to be purely a physico-chemical one, and not due to any vital activity of the red cells. The hæmoglobin we have described is a comparatively dark red compound, and we find it only in venous blood. When this blood returns from the lungs by the pulmonary veins it is brightened, and no longer contains any hæmoglobin as such. For each molecule of hæmoglobin has now added to itself two atoms — that is, one molecule — of oxygen gas, forming a new compound, called oxy-hæmoglobin. This is brighter in color, and is a true, though loose, compound, as we can prove by studying its spectrum. Specimens of blood containing hæmoglobin and oxy-hæmoglobin respectively produce different effects upon light transmitted through them, as we see when we look at them through a spectroscope. This spectroscopic examination of the blood is important, also, from the medico-legal point of view, as it may determine the cause of death from asphyxia, as also death due to gas-poisoning in sewers or coal mines.

In brief, then, the hæmoglobin of the blood becomes oxy-hæmoglobin in the capillaries of the lungs, and this oxy-hæmoglobin is reduced to hæmoglobin again in the capillaries of the body. We have here the explanation of the pulmonary or lesser circulation; and we learn, also, that the term artery, or "air-carrier," is not quite a misnomer after all, since the arteries do carry air, or its chief constituent, from the lungs to the tissues, in this fashion

Why anæmic people are given iron by the doctor in their medicine

Oxygen is always found dissolved in the fluid of the blood, but such solution could never begin to be adequate for the needs of the body. The virtue of oxy-hæmoglobin lies in the extraordinary condensation of oxygen which it makes possible, and that is the virtue of the red cells. No wonder that the anæmic girl is easily made out of breath, for she has too few red cells, and too little hæmoglobin in what she has. According to Larrabee, in the *Journal of Medical Research*, the average number of red cells per cubic millimeter of human blood is 5,267,250 in males and 4,968,667 in females. Only in such numbers can the red cells convey enough oxygen for the purposes of the tissues. There is reason to believe that their lives are brief, probably lasting only a few weeks. Thus they must be incessantly produced in enormous numbers, a process which involves the ceaseless activity of the bone-marrow and a continual supply of iron in the food. The cells that are worn out appear to be broken up chiefly in the liver, though also, probably, in the spleen and elsewhere; and it is from the coloring matter of the effete cells destroyed in the liver that the bile obtains its color. The color of the excretion of the kidneys is also derived from broken-down yellow-red cells.

Some of the unsolved problems of the constituents of the blood

Why the lives of these cells, whose function is so simple, should be so brief, involving such incessant replacement of them, is not obvious, but the writer would suggest that they are already doomed to early death when they lose their nuclei, and that it is this early loss which determines the shortness of their lives thereafter. The cells of the corneum, or outer layer of the skin, similarly lose their nuclei, and perform the mechanical function of protection, but they die soon afterwards, and are replaced from below.

The blood also contains a large number of minute flat objects, called blood-plates, which have no visible structure, and, as Wright has demonstrated, are not cells, for at no stage of their existence do they contain a nucleus. Their function, however, is not understood.

Much less numerous than the blood-plates, but of proved and understood importance, are the white cells. These constitute the third and last of the organized elements of the blood. They present almost every possible contrast to the red cells. They are relatively very few, in health, the blood containing not more than 9000 or 10,000 for every 5,000,000 of the red cells. In certain conditions the numbers are diminished, as in chronic alcoholism, and in a multitude of other conditions their numbers are greatly increased, for a purpose lately discovered. Their lives cannot be very long, but we do not know where, nor how, they die and are disposed of in health. Though they possess nuclei, they do not multiply in the blood. Their source and origin can be traced when we study their different forms.

Cells that act as guardians of the body and eat harmful intruders

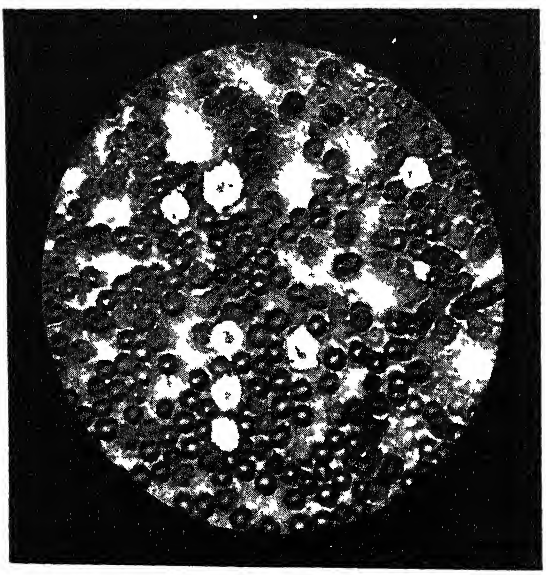
For, unlike the red cells, these white cells or leucocytes are of many different types. Students of the blood are not yet agreed as to the relation between them, but it is certain that some of these types are younger and less mature forms of others. Though all have nuclei, these nuclei stain differently in different types, some being shown up by acid and others by alkaline dyes. This indicates a radical chemical difference between them. The most numerous form has a large and very irregular segmented nucleus, of such a shape that it was long thought to be several nuclei, and these were at first called multi-nuclear leucocytes. Now that we know that the nucleus is all in one but in various segmental arrangements, we call these cells the "polymorphoneuclear" leucocytes. It is almost certain that these represent the fully mature and active state of another type, smaller, rounder, and having a large spherical nucleus that almost fills the cell. These appear to do no work, and probably they change into the larger and more numerous kind as they grow older. The smaller, regular-shaped cells are called lymphocytes, and we know for certain that they are added to the blood as it passes through what is called lymphoid tissue, in many parts of the body.

This lymphoid tissue, examined under the microscope, is found to consist of little more than a dense multitude of round, young cells, which are about to become lymphocytes, and to be added to the blood-stream. When we learn the function which these cells will develop, we need not be surprised that bacteria and other enemies of the body are often arrested and attacked in lymphatic glands, or at the fact that, in such a disease as malaria, the spleen is so greatly enlarged. The surgeon may often be inclined to wish that there were no glands in the neck, to swell with tuberculosis, and require removal, but if we look into the principles of bodily construction we learn that the lymphatic glands are, in many instances, the body's first line of defense; and it is much better that dangerous microbes should be arrested and have to be dealt with in them than that they should pass on unchallenged to more vital and indispensable organs.

The function of the leucocytes has long been a puzzle, but the pioneer work of Lord Lister on inflammation, and the later researches of Professor Metchnikoff, have answered the question in a most remarkable way.

Lord Lister found that a drop of pus, or "matter" formed in inflammation, contains many dead leucocytes, though no blood-vessel may have been damaged. Metchnikoff studied the behavior of certain cells in a minute organism called the water-flea, and in due course the facts were discovered. The actual passage of leucocytes of certain kinds through the walls of blood-vessels has been observed, and we know now why Lord Lister found them in pus. They have also been observed to do very real things inside the blood-vessels in certain invasions of the blood, and hence Metchnikoff has given to the mature form of leucocyte the name of phagocyte or "eating-cell". But only certain kinds of the leucocytes are phagocytes.

Whether the leucocytes have any function worth mentioning in health has long been doubted, but probably some of them may help to convey particles of food from the bowel to the body generally. But, for the rest, their function in health is perhaps like that of the sentinel or the policeman in times of peace and order. They are simply patrolling the body politic. If enemies enter the blood itself, as the parasite of malaria does, they are eaten there; if they do not enter the blood itself, the phagocytes leave the blood-stream and pursue them in the tissues, as marines may disembark and fight upon the land. We have seen elsewhere that the capillaries leak in both directions, and we have had reason to infer that they leak both gases and fluids. But they are also capable of being traversed by the phagocytes, very slowly and with much labor, so that not a single red cell follows and is lost — for red cells are only useful in the blood. This "emigration of the leucocytes" evidences a vastly higher capacity of sensation, and of devotion, than if they merely repelled invaders in the blood. It depends, as their actual eating does, upon their power of independent movement, called amœboid, or amœba-like, because of its resemblance to the behavior of the amœba, which mature leucocytes resemble in so many other ways. But leucocytes are human, nevertheless, and exist for the body to which they belong and which gave them birth. There is a form of amœba which is parasitic in man, producing the dread disease dysentery; and in such cases we see fight between the amœba that is an amœba, and the human cell which has assumed, or resumed, the form and behavior of the amœba for the purposes of man.



A FEW WHITE CORPUSCLES OF THE BLOOD, TOGETHER WITH A NUMBER OF RED CORPUSCLES
Enlarged about 1000 times in a microphotograph by A E Smith.

One most notable fact of the behavior of the white cells must be noted. Wherever the body is threatened they multiply to an incredible extent, for the purpose of its protection. When injurious microbes make an entry into a wound, or otherwise, the whole body, as a single and devoted organism, wholly organized, coordinated and mobile, devotes itself to the business of defeating them. Whether the danger threatens in the brain, or the valves of the heart, or under a toenail, the same devotion, sacrifice, efficiency and concentration of purpose are found in every case.

Here we need only note further that the call to arms is not nervous, but chemical. Products of the local conflict enter the blood and are carried everywhere, stimulating production of new leucocytes in every portion of lymphoid tissue in the body.

The three gases that are dissolved in our blood, with good and bad effects

We turn now to the fluid part of the blood, and may conveniently begin with three gases which we find dissolved in it. The first, nitrogen, has been absorbed from air in the lungs, and does nothing in the body; the oxygen and its carriage we already understand, for that depends upon the red cells. The carbonic acid remains, and we must trace its carriage and destiny as the correlative to that of oxygen. We found that one of the differences between arterial and venous blood is that the red cells of the former contain oxy-hæmoglobin, and of the latter hæmoglobin. Similarly we find that arterial blood has no carbonic acid dissolved in it, but venous blood has. It is thus only in this degree that carbonic acid is one of the gases of the blood, and we may add that venous blood has no oxygen dissolved in its fluid part.

The delicate chemical balance that keeps the blood purified and reinvigorated

The cells of the blood appear to take no part whatever in the carriage of carbonic acid from the tissues to the lungs. The whole of this work is done by the fluid, which, we noted, was inadequate to dissolve as much oxygen as the tissues need. But, on the whole, the oxygen carried in one direction and the carbonic acid carried in the other are comparable, and, indeed, the fluid of the blood could not dissolve the carbonic acid which it must convey. An exactly similar solution of the problem is obtained as in the case of the oxygen. The carbonic acid gas unites to form a loose compound with certain salts of the blood, especially sodium carbonate, forming a bicarbonate, as it is called, in venous blood — *i.e.*, a salt containing twice as much carbonic acid as a carbonate does. In this way the carbonic acid can be tightly enough packed; and just as the oxygen dissolved in the fluid of arterial blood is only a small proportion of what it really conveys, so the carbonic acid dissolved as such in the fluid of venous blood is a trifle compared with what the carbonates of the blood are carrying loosely with them.

In the capillaries of the tissues generally, carbonic acid, formed by their life as in the burning of an ordinary fire, is absorbed by the blood, more or less balancing its loss of oxygen to the tissues. In the former case, carbonates become bicarbonates, and simultaneously oxy-hæmoglobin becomes hæmoglobin, and the tissues gain oxygen. Exactly the reverse of both of these processes obtains in the capillaries of the lungs.

The blood in a man's veins as individual to him as his features

We shall soon have to study the lungs and the process of respiration; meanwhile we note that the interchange of gases observed in the capillaries of the tissues generally is the *real* breathing, or "tissue-respiration," as it is called. It is for this tissue-respiration that we breathe, and for the lack of it that we die if the circulation of the blood ceases. Death from heart failure, no less than from drowning, is thus death from suffocation or lack of air.

The chemistry of the fluid of the blood is a profound subject, still in its infancy. We have lately found that not only is its composition different in different species and races, but actually that the fluid part of the blood is unique in every individual — personal and peculiar as his face. But many facts are common to all men. The blood contains a quantity of water — which it is always losing and which must therefore be always replaced. We drink water in order to maintain the due proportion of it in the blood. In this water are dissolved, besides the gases named, a multitude of other substances, which have much interplay between them, so that the problem is as complicated as that of the composition of sea water — and a thousand times more so. The constituents vary in complexity from peculiar proteins, called serum albumin and serum globulin, to such familiar but no less essential salts as sodium chloride, or common salt, which is necessary for various reasons, as that without it the globulin of the blood would coagulate. The albumin and globulin of the blood are in incessant distribution to tissues to replace their ever-wasting substance, and require frequent replacement.

The element in the blood that rushes to the rescue when anything goes wrong

We consume albumin in milk, white of egg, meat, bread and so forth, but none of these is serum albumin, and they all require to be changed into serum albumin if they are to enter the blood. If egg-albumin be injected into the blood-stream, it acts as a poison, and is removed as soon as possible. These facts give us some preliminary idea of what digestion involves.

A third protein of the blood is not in incessant distribution. It is not for food purposes. Its name is fibrinogen — *i.e.*, fibrin-maker; and its function, like that of the leucocytes, is not for normal states of the body, but for its restoration to the normal when things go wrong. From the standpoint of heredity and the adaptation of the body, nothing is more wonderful than the presence of this compound in the blood, for no purpose but to solidify, if hemorrhage should occur, and thus to arrest it.

The healing processes that may be seen where the blood clots after an accident

So long as the body leads its normal existence, the fibrinogen does nothing. But let a capillary be torn, and at once the blood solidifies around it and exemplifies the "natural arrest of hemorrhage". This familiar process of blood-clotting is a series of marvels. The fibrinogen, which must, of course, be fluid when it is not wanted, undergoes chemical change, converting it into solid fibrin, by the action of a ferment in the blood, called thrombin. But if this ferment always existed in the blood it would form fibrin and arrest the circulation. Therefore it only exists in undisturbed blood in the form of prothrombin, as it is called. When a hemorrhage is brought on due to the injury of certain body cells, a ferment is set free from the injured cells. This ferment unites with the prothrombin in the presence of the calcium salts and then thrombin is formed. The thrombin next unites with the ever-present fibrinogen to form fibrin. This sticky fibrin ensnares the red and white cells and blood-plates to form the clot: the breach in the vessel is sooner or later closed, unless it be enormous; and by a series of subsequent processes, which involve the whole physiology of repair, the fibrin and the leucocytes build up new tissue and mend the torn vessel.

The blood has lately been shown to contain many more compounds chemically resembling these three — the "hormones," which stimulate one tissue or organ, having been produced and added to the blood by another; the "opsonins," which act on the microbes and help to make them eatable by the phagocytes; and various "antitoxins" and "immunity" agents, which protect the body from, say, smallpox, having been added to the blood in the processes which are started by vaccination.

The one sugar and the many inorganic salts that are in the blood

Other organic food substances must be noted, the chief of these being the special form of sugar called glucose. No other sugar can exist in the blood; and all other sugars we consume, whether in milk, or fruit, or sweets, together with all the starch in the food, are converted into glucose and circulate as such in the blood.

The inorganic salts of the blood are very numerous. The metals represented are chiefly sodium, potassium, calcium, magnesium; and these form various salts, especially chlorides and phosphates and carbonates. The blood also contains waste products such as urea, and a sodium salt of uric acid, on their way to be eliminated through the kidneys, with more or less success.

In all but a few details, the foregoing is no more than a mere outline of the elementary facts and principles of the new science of hæmatology, or the study of the blood. Many illustrious men of science are now devoting their whole lives to it, for it holds the key to half the problems of individual difference, of immunity from, recovery from, and susceptibility to disease, of efficiency, happiness, longevity. It is not the life, but it is the key to the life. Verily just is the universal instinct of man which reckons the first of all crimes to be the "shedding of blood".

HOW AND WHEN TO SLEEP

Sleep, Its Measurement, Length, Depth, Natural Production, Daily Rhythm, Disuse and Wooing

THE MODERN NEED FOR A SLEEP SOCIETY

WE are somewhat in danger of forgetting how to sleep nowadays. Almost every other aspect of personal hygiene has its students and enthusiasts. Societies are formed to advocate this and that; and endless controversies, which interest us all, rage about large and small matters of exercise, clothing and, above all, the minutest and most trivial details of diet. But there is no Sound-Sleep Society — though many societies, otherwise named, illustrate that ideal — and no one who is not an expert realizes the importance of this subject, alike for the adult, for the elderly and for childhood. The modern world is forgetting how to rest and how to sleep.

This is the obvious and familiar remark as regards the bustle and speed of our lives. People agree that there is something wrong, and deplore the prevalence of nervousness, nerve-exhaustion or neurasthenia, hysteria and actual insanity. But for some reason or other they do not realize that our business is to study and appreciate the practice of leisure, rest, recreation and, above all, the due cult of "Nature's sweet restorer, balmy sleep". We all need restoring, at times; and we take tonics and stimulants and exercises, and change our diet on broad or narrow lines, or seek a change of air, and yet neglect the "sweet restorer" with which nothing else can compare.

It is quite possible to cry with the urgers of preparedness "Wake up, America," and to argue that much national danger and much personal ill-health are due to lack of action, and yet to preach this gospel of sleep.

The gospel of work is a good and very necessary one, and no student of hygiene, knowing that inactivity is the road to death of any function or organ of any living being, can ignore it, but the whole point of the present argument is that good work and good sleep promote and are the conditions of each other. Both are characteristic of health, and there can be no real health without them. Only the man who sleeps well wakes well, and only the man who wakes well sleeps well.

The distinction between what we call sleep and what we call waking is only relative. There is a continuous gradation, in reality, from abnormal and, so to speak, morbid sleep at one end, through many stages that are normal, up to abnormal and morbid excitement at the other end. At the lower extreme, not far short of death, is the deep unconsciousness produced by narcotic drugs in sufficient dose, by morphia, chloroform, alcohol, ether, etc., in apoplexy, coma and also in the curious condition called catalepsy. Higher up the scale we come to the very deep sleep which betokens exhaustion or long lack of sleep, but which appears to be normal and customary in some people. Then come the various levels of good, sound sleep, one of the most precious of possessions, and the certain condition of many more. The characteristic of this kind of sleep is that it is dreamless, as we hinted in our description of the healthy man. Perhaps no sleep is really dreamless; indeed, many psychologists say so. But when we use the word we usually mean that there is no recollection of any dreams, and in that sense good sleep is dreamless.

No doubt there are many people who seldom or never attain this kind of sleep. They are never quite asleep, and very likely they are never quite awake. It would probably be worth their while to try to improve the quality of their sleep, though the modern hygienist is bound to admit the natural variability of mankind, in this as in all other respects, and to qualify the expectations of those who think that anything is possible to determination and patience.

Somewhat higher up the scale come the light kinds of sleep, of the "forty winks" pattern, when we dream a good deal, even imagine and invent and anticipate and remember a good deal, partly know where we are, and are apt to deny that we have been to sleep at all. From such sleep we are, of course, very easily roused; and some people seem never to get much more than this kind of "cat-sleep," as it is sometimes called. But though the amount of noise required to wake a given sleeper is usually a good and trustworthy index of the depth of his sleep, and has been experimentally used to study the depth of sleep from hour to hour, we must remember that people's ears vary widely in sensibility; and some who have good, sound sleep may be very easily wakened, and may wake wholly and quickly in a second.

The power of paying attention regarded as a measure of sleepiness

At this point the stages crowd upon one another, and may be missed, like the stages between the liquid and the gaseous state of water, but they are there, nevertheless. Anyone who has listened to a dull lecture or read a sleepy article knows how attention flags and returns; we are in the intermediate stages. Those who have observed themselves may have noticed, also, how on going to sleep the train of thought is occasionally lost, and one cannot regain it, as if a thread or two of the texture had dropped below the level of consciousness, while most still remain above submergence. Other people, no doubt, go to sleep quickly and all-of-a-piece, just as many people wake.

If we think, we shall see that the stages of waking or wakefulness are many. There is lazy attention or half-attention, as of the old man who, speaking the honest truth for most of us, said: "Sometimes I sits and thinks, and sometimes I just sits." He was sometimes awake enough to think, and sometimes only awake enough to sit. We must sharply distinguish between this state and that of genuine absent-mindedness, or absorption, which may be intensely wakeful, but asleep to present surroundings. The two states may be judged identical by other people, but are profoundly opposite. Next there comes the ordinary waking state when we are all there, and attend duly, without being incapable of having our attention diverted. Beyond this there are many stages of excited and tense attention, as of the soldier who is so awake to the fight that he is unconscious of the bullet in his leg, leading up to the intense and passionate and dangerous absorption of ecstasy, usually religious in form, or of agonized and sleepless grief.

Is it possible to measure truly the amount of our effective sleep?

The table of stages is a long one, but it is worth reviewing, because no one who has not the idea of it in his mind is really prepared to understand anything about sleep, and also because such considerations as these help us if we are inclined to make any intelligent study of the most interesting and available thing in the world, which is our own minds and their processes.

If sleep has all these variations in depth, how are we to measure them? The measurement must be made, for practical purposes, and certain means are available. It will no longer do, then, to assume that the quantity of sleep can be measured by the clock. That is no more possible than it really is possible to measure a man's age, as if he were a tree, by the number of our planet's revolutions round the sun. The clock can only measure the length of sleep, but the length of sleep is of comparatively small importance compared with its depth, which the clock cannot measure.

THE KINDLY MORPHEUS WHO BRINGS TO TIRED MORTALS THE TIMELY DEW OF SLEEP

Sleep was regarded by the Greeks as so great a mystery that they imagined it as under a presiding deity whose messenger was Morpheus, represented in the above picture by W. Reynold-Stephens as bringing his whispered charm.

No one's health, sanity or efficiency can do without a certain minimum of sleep; and it is a mistake to assume that, if one man gets five hours and another ten, the first needs only half as much as the second. If his sleep be twice as deep, he gets as much, but he gets it quickly. This is a very precious faculty for the worker; and if it can be learned, which may in some degree be possible, the learning is worth while.

The best test of how we sleep to be found in the feeling of refreshment

One hour of sleep of the best quality is worth many hours of the worst. Indeed, most of us have had the experience of a kind of partial sleep which exhausts instead of refreshing us. We should have done better not to have slept at all in that fashion, but to have spent the time in placid, easy wakefulness, as many wise old people learn to do when they cannot sleep. On all these grounds the measurement of the depth of sleep is worth undertaking, not least because we require to learn, with our modern habits, whether it is really true that an hour before midnight is worth two afterwards, and whether that early sleep is really entitled to be called one's "beauty sleep," as the phrase goes.

The two methods by which the depth of sleep may be measured

The depth of sleep may be measured by its results, as doctors and nurses soon learn to do. They observe the degree to which the patient is recuperated, and they know how deeply he must have slept.

Secondly, the depth of sleep can be tested by experimental stimulation of the sleeper. Such students as the Indian thieves who will steal a blanket from under a sleeping man without waking him make experiments of their own. More academic physiologists can employ any graded stimulus of touch or sound, and observe at what stages the greater stimulus is necessary to wake the sleeper. The results are definite and interesting. They do not justify the assertion about the comparative value of sleep before and after midnight, but they explain it, as also the phrase about "beauty sleep".

They show that six hours of sleep are by no means equal to twice the first three, for we sleep deepest at the beginning — not of the night, but of our sleep, whenever that may be. It matters nothing, in itself, when one sleeps, though natural light is better than artificial light to live and work by, and our sleeping habits may tell in that way. But so far as the sleep itself is concerned, we sleep deepest in the first few hours; and then our sleep gradually becomes shallower and shallower, until we waken — spontaneously, as we really should do, because consciousness has reached the surface again, in the convenient metaphor the use of which psychologists can scarcely avoid.

How far may dreams be a guide to the quality of our sleep?

Thirdly, the depth of sleep can be measured, as we have already hinted, by the dreams. This, indeed, is where the study of dreams finds its value today, and this is where they may indeed be held capable of predicting the future — for the man who habitually has coherent and well-remembered dreams, especially if they be repeated, may look upon them as rather ominous, whatever they may be about. He is probably not getting a good quality of sleep, and should see to it. Best of all is to have no dreams; or, if we all must dream, to have no remembered dreams. Next best is to have one's dreams few, undistressing, and so incoherent that they can scarcely be pieced together afterwards. Definite, clearly articulated dreams, which we can recall in detail, are less satisfactory, for it seems probable that they involve the action of more areas of the brain, and thus mean that more of it was awake at the time. Worst of all are nightmares, which are a real evil, definitely condemnatory of the quality of sleep, and demanding serious attention. Nightmares are frequent in one particular form of heart disease, which is not common, and is becoming even less so. As a rule, the disturbance which so uncomfortably excites and half awakens the brain in these cases is to be found in the stomach or some other part of the digestive tract.

The parts of us that "go easy" but never sleep while we rest

And now let us see what sleep consists in, and what are the characteristics for health of this state. This inquiry is part of physiology, strictly speaking, but it is so close to hygiene that we must treat it here.

No one knows what happens when we sleep. To understand sleep entirely would be to understand waking, to know what mind and consciousness are. But some things we do know. The whole nervous system cannot afford to sleep. Breathing must continue, and the control of the heart, each of which involves the sleepless activity of certain nerve-cells. The heart itself cannot sleep, but must content itself with the rest it gets between its beats. Nevertheless, everything "goes easy" during sleep, as far as possible. The muscles are relaxed, losing their "tone" and so getting rest. This cannot apply to the breathing muscles, but breathing is somewhat slowed, as the bodily work is now reduced to that of the heart and the breathing muscles themselves, so that comparatively little oxygen is needed, and comparatively little carbonic acid is produced. The nerves governing the size of the blood vessels relax their orders, and the vessels on the surface of the body are seen to dilate. The kidneys do but little work during sleep; and if there is marked evidence to the contrary, disorder of the kidneys may reasonably be expected.

The need for refreshing in sleep the ceaselessly active nerve-cells

As we have seen, even the middle areas of the nervous system may not sleep entirely during what we call sleep, but the uppermost centers — those which are concerned with the waking consciousness and the expression of the Self — these do indeed sleep, after their unbroken and wonderful activity of so many hours in succession. We should remember that a period of waking, say, of sixteen hours, means the ceaseless and watchful functioning of millions of nerve-cells; and the real marvel is the machinery of nutrition and of drainage of waste products whereby these cells can be kept going without a moment's intermission for so long a period. Further, we are to note that sound sleep means the relaxation of all emotion, and emotion is a very costly business, involving great nervous wear and tear. So much the less satisfactory is that sort of sleep which includes nightmares and other dreams, with their emotional cost.

Need of sleep for the young who are growing and the old who are resting

In the case of the child we further find that sleep is the period of growth and development. Those processes are retarded where children's hours of sleep are too short, or where they live in too much noise — a matter of national moment, and profoundly affecting those children's personal health in later years, including, probably, their capacity to sleep soundly. There is reason also to suppose that sleep is no less important at the other end of life. We commonly say that the old need less sleep, which appears at first sight to be true. But it may often be that they cannot get more sleep, for they are losing the capacity for sleep, and that they grow the older in consequence of the loss of this great restorer. Those who have care of old persons whom they love should try to promote their sleep, persuade them, like young children, to sleep after the midday meal, and so to prolong their years, as there is every reason to expect.

Sleep is above all sleep of the brain — more so than of the rest of the body. It is therefore closely related to disease of the brain; and lack of sleep should above all be attended to in persons whose nervous systems are unstable and who have a tendency to insanity.

Sleep more nourishing even than food — "who sleeps, dines"

When the whole evidence is summed up in this fashion, and when it is added to the vastly more weighty evidence of daily and nightly experience, we may begin to appreciate the profound justice of the words which Shakespeare put into Macbeth's mouth, when he calls sleep "chief nourisher in Life's feast."

The French express the same idea, but less forcibly, when they say: "*Qui dort dîne*" — "Who sleeps, dines." The truth is that he who sleeps does much more than he who dines. For sleep is not only the equivalent of food — it is the "*chief* nourisher in Life's feast." The evidence of illness proves this at once. Here we find that the patient must sleep. Food is an entirely subordinate matter. Probably the patient cannot digest. In any case, the body has reserves of nourishment, if only it can cope with the poisons that threaten it. Sleep will save it, economizing its profoundest forces, and enabling it to avail itself of its innermost resources. The skilful doctor knows that food will probably not be digested, and, in consequence, will interfere with sleep — which is precisely the last way in which to keep the patient's strength up. On the other hand, he knows that the right kind of nurse or friend, who will not worry about food, but whose influence is soothing and may induce sleep, may well mean the difference between life and death to his patient.

The unexplained mysteries of sleep, physical, chemical and hypnotic

What happens in the brain to produce sleep we cannot say. Physical or chemical changes, or both, must occur; and the problem is not entirely unpractical, for the solution of it should help us to control sleep and produce it safely. It is well known that the cells of the brain have a large number of short branching processes, radiating from them, which are called "dendrites". These dendrites, unlike the long processes of nerve-cells, appear not to communicate with other cells so much as to nourish, in some way, the cell to which they belong. They are observed to be damaged in certain chronic degenerations of the brain-cells, such as are observed in alcoholic insanity. It is also asserted that, during sleep, these dendrites are withdrawn, or partly withdrawn, into the cell to which they belong, so that we may suppose it to be deprived, for the time, of its "feeders". Another theory of sleep is chemical, and leads to notable conclusions.

According to this view, which cannot but be part of the truth, though it is doubtless not the whole, waking and sleeping depend upon a chemical rhythm within the body. While we are awake we gradually produce and accumulate a certain substance or substances, which we may call the "natural hypnotic". The store of this substance in the body slowly mounts up, its quantity being largely dependent, normally, upon the degree of our activity, whether mental or physical. At the end of the day the quantity becomes such that we feel ready for sleep; and in favorable conditions of quiet and darkness — such as every hypnotic is entitled to — we sleep. Let us observe how this theory tallies with the diurnal rhythm of the normal man.

When the dose of this natural hypnotic has mounted high enough, he sleeps well and deeply. Gradually it begins to diminish in abundance, no more being now made, and the intensity of his sleep is reduced, as we have already seen. Meanwhile, no doubt, his brain-cells are also accumulating food-material, of which they have been partially exhausted; and now the man wakes. But if we observe him closely we find that he is not yet at his most wakeful. Even after obvious waking most of us require a few hours before we become as awake as we may be. Most people are not at the "top of their form" in the early morning; it is in the early afternoon, normally, that we appear to become most fully awake, and then, after a time, slowly sleepy again.

The time-table of the body, bringing us into a state of rhythmical rest

There is thus a daily rhythm which, though it appears to consist of two abruptly marked phases, is really continuous, but how smooth and continuous we can scarcely guess unless we adopt the practice of going to bed when we feel sleepy, and allowing ourselves to waken spontaneously.

The recurrence of this rhythm, it is here suggested, may well correspond to the chemical theory of sleep. We awaken when our natural hypnotic diminishes in quantity, though we do not fully waken until it has diminished further; and then

our full waking begins to increase its quantity again. The evidence as to the rhythm in the waking hours is partly derived from the experience of people who have to write and lecture. It is familiar to singers that they cannot nearly do themselves justice in the morning — not until their voices have got warm, as they put it. And it is the fact that the various athletic records are made in the afternoon. A sprinter is perhaps a couple of yards faster as the phrase goes, at 2.30 P.M. than he was at 9.30 A.M. His nervous system is now completely awake, and everything is capable of going at its smoothest and quickest.

No brief assertion, however, will encompass the facts of anything so complicated as sleep. There can be no doubt that the quantity of blood in the brain is one of the factors of sleep. Professor Angelo Mosso (1846–1910), of Turin, most celebrated as a student of fatigue, made many experiments with a table so exquisitely balanced that it would lie horizontal with a man upon it, but respond to any change in the distribution of his weight. He found that, when such a man was asked to do a sum, the end of the table where his head was at once began to sink, because of the increased quantity of blood which flows to the brain, as to any other organ, when it is being called upon for active work.

The problem of the amount of blood in the brain in relation to sleep

Such observations, and many others, lead us to suppose that the quantity of blood in the sleeping brain must be diminished. They help us to understand why one should be warm enough in bed, meaning that we have plenty of blood in the skin; they partly explain the serious objection to cold feet in bed, and the fact that toasting the toes at the fire after a hearty lunch, and thus liberally supplying the feet and the digestive system with blood, may markedly promote sleep, notwithstanding what we have said about the natural rhythm of sleep and waking. Even so, we must not overstate the facts. The evidence suggests that a *too* bloodless or anemic brain cannot sleep.

In many cases of sleeplessness, especially among the elderly, whose arteries are beginning to stiffen and cannot relax as they should, doctors believe that this is the cause, and they employ warm drinks at night, and other means of relaxing the arteries in the brain, and succeed in this way in producing sleep. Thus the sleeping brain appears to be one in which there is definitely less blood than in the alert and waking brain, as we should expect.

The activity of the body as one of the most natural inducements to sleep

All the foregoing facts consort with the view that activity modifies the composition of the blood, and is associated with the production of something which, in suitable dosage, promotes sleep. Busy days make balmy nights; and the business may be of mind or of body. One of the facts discovered by Professor Mosso was that physical exercise produces certain chemical compounds which lower the activity of the whole body. We may say, from one point of view, that they produce fatigue, and from another that they are natural sedatives. It is not merely the muscles involved in the exercise that are involved in its results. Violent and prolonged exercise of the legs tires the arms (though in much less degree), and vice versa, for the fatigue-products are carried by the blood to all parts of the body. They are carried to the brain, and, on the one hand, help it to sleep, and, on the other, interfere with its working power. It is true in some ways that a change of occupation is rest, but a delusion in others.

We must work hard in order to sleep better, deeper and more dreamlessly

We have done our boys and girls much harm, in the last few decades, by assuming the entire truth of this doctrine. Only too often we have set them to games and physical exercises, and then have expected good brain-work from them, not knowing that we have altered the composition of the blood in a manner which "rests" the brain only in the sense that it predisposes it to rest and thereby interferes with its continued activity.

Work, then, under certain conditions afterwards to be defined, would appear to be the best hypnotic — probably because it involves the production of the natural hypnotic. That is the chief contrast between work and worry, and the chief condemnation of the undiscernment which attributes to one the effects of the other — as we shall see when we come to study worry, that arch-enemy of health. Work promotes sleep; work harder, and you sleep better, sleep deeper, and dream less — which is the sure sign of improving sleep. Work harder still, and you fall asleep at your work — admirable and protective arrangement. But when we say work we mean work and nothing but work — pure, uncomplicated activity of any order. Introduce but a tincture of worry into the work, or omit the work altogether, leaving the worry, and sleep vanishes, no matter how softly rich the couch.

Hard work should be harmoniously balanced by deep sleep

There is a definite relation between work and the need for sleep — and its quality. The hard worker should be a proportionately deep sleeper. The idea that only the brain is refreshed by sleep, or that only brain-work requires sleep, is absurd. Sleep is much older than the modern brain. Hard muscular work involves the need of sleep, even though sleep be, above all, rest of the highest areas of the brain — which are not involved, we might suppose, in muscular work. But muscles are only driven by the orders of nerve-cells; and much of what we call muscular fatigue, because it shows itself in the muscles, is really nerve-cell fatigue or exhaustion, not to mention that the by-products of muscular action reach the nervous system and affect it. The brain works, in its way, when muscles work, and the physical worker requires due rest. Fortunately, he gets it. Only the happy child gets the constant quality of unfailing sleep which is the blessed portion of the man who works all day in the fields, and who has no nervous distress or worry to complicate the naturally hypnotic quality of his work.

Most of us are brain-workers nowadays, in some degree whatever our "job" may be, and have to face a novel problem. It is an instance of what Professor Metchnikoff calls the "disharmonies" of our constitution. The contrast between the difficulty with which, too often, the brain-worker obtains sleep, and the case of the manual worker, suffices to show that man, as at present constituted, is better adapted for physical than for mental work. This "disharmony," like many others, is due to our amazing development of brain — while the body and its needs persist. Given that one has to have a body, there is a danger in habitually sedentary mental labor, a danger which most of us must avoid by a little personal wisdom. We must take our daily exercise as well as our daily bread — probably a little more of the one and a little less of the other.

The difficulty when the nerve-machinery runs overtime and will not rest

Further, we must note that, just as the nervous machine requires some time for warming up in the morning, so it is very apt to go on working when its activity is no longer desired.

At both ends of the day one should recognize the indications of the natural rhythm, as indeed most of us do. To read the paper and to answer one's letters is less hard work than to originate, invent, advance — which we keep until the other is done. And at night, though the quiet and the security from interruption offer many temptations to the brain-worker, we should gradually relax our ardor. If we are going to spend an hour or two on really hard work, such as study of any kind, it should not be the last at night. We shall get better results from the same time when the brain is fresher and attention is easier. Let the last hours be easily spent, especially if getting to sleep is a problem.

If we appreciate the physiology of sleep, as regards the relative distribution of blood to the skin and the brain, and also as regards the more lazy breathing, we shall see that people who suddenly make the change from a stuffy bedroom to a properly ventilated one may find that they cannot sleep.

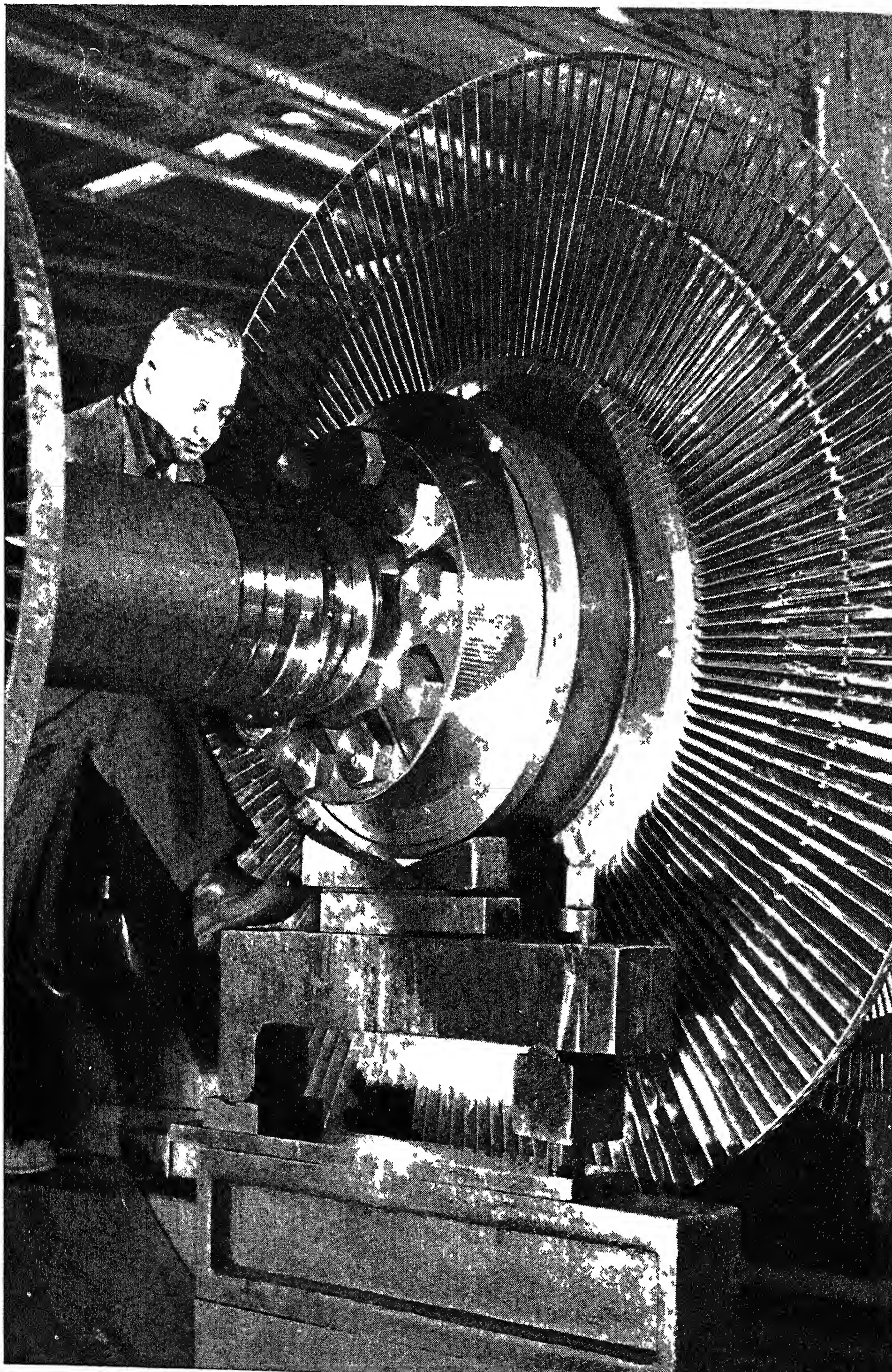
Carbonic acid gas, which we expire when we breathe, is the natural narcotic, and does its blessed work in soothing almost every death-bed, all the fictions about the "death-agony" notwithstanding. Thus, if we go to bed in an unventilated room, where it is easy to be warm, and where the proportion of carbonic acid in the air soon rises, we shall find it easier to sleep than at first, when we take to purer and cleaner conditions. Doubtless, also, the transition from a feather bed to a spring mattress seems less comfortable and sleep-inducing at first, though the feather bed seriously interferes with personal ventilation, and should disappear from all households.

Some practical hints about the sleep-inducing arrangement of beds

The remedy is to recognize that a sleeper is entitled to warmth. Keep the window open, sleep on a proper bed, and by all means throw on an extra blanket if it be needed — a simple remedy. And since we are so far, the question of the bed may be settled once and for all. A bed should be single; the regular practice of sleeping with a bedfellow cannot be really hygienic. The modern fashion of twin beds side by side, for husband and wife, is a great improvement. A bed should be wide enough to permit of a fair amount of movement, and need be no wider. Let the clothes be wide, and cold need not be feared. There should always be a blanket between the under-sheet and the mattress. Dark coverings, of the rug pattern, are to be questioned, like anything else that "keeps clean a long time" or "doesn't show the dirt". Dirt is just as much dirt whether obvious or concealed. Many cleanly people seem to forget that one's bed is as personal as one's underclothing, and scarcely less exposed to the products of one's person. Probably, also, many varieties of infection, such as that of a common cold, to name nothing more serious, are retained by the outer coverings of a bed, to do future damage.

Of course, a bed should have no canopies, curtains, or any of the other devices with which our forefathers suffocated and devitalized themselves, and stored infection. If any critic should suggest that our ancestors' practices, here or elsewhere condemned, "did them no harm," he evidently has the onus of explaining why their death-rate was so much higher than ours

But before we proceed to study in detail the problem of obtaining sleep and recovering it, in health and in disease, let us completely satisfy ourselves that this is a too often neglected problem of the first importance. Above all does it matter for the nation's childhood. There can be no doubt that children require more sleep than grown-up people, and the younger the child the truer this is. An adult needs the rest of sleep to renew the energy that has been used up in the hours of wakefulness. So long as his body can maintain itself, the effect of each night's sleep balancing the loss caused by the wear and tear of the day's work, all is well. But the child's body has to develop and grow, that is, has to *make* as well as *maintain* itself. When it is awake it takes the food by which it grows, but the real growing is done when it is asleep. Then the body uses the food which has been taken in the daytime and builds it into itself. If a child, especially a baby, does not get sufficient sleep, it cannot grow properly. It is a popular theory, not far wrong, that a child sleeps half its time, an adult one-third. In very early life the cerebral faculties appear to be easily exhausted, and during the frequent and prolonged sleeps of infancy the brain rests and the vegetative changes connected with nutrition and growth go on actively. As life advances less sleep is required, until in adult life a period of seven or eight hours is sufficient, although some individuals require more sleep than others. As a rule women require more sleep than men, but it is largely a question of habit — as, for instance with nurses who often work for weeks on end with only snatches of sleep amounting all told to not more than two or three hours a day. But sooner or later, even in these cases, nature asserts her demands and prolonged sleep is necessary to maintain health and vigor. The account with sleep cannot be indefinitely overdrawn without physical bankruptcy.



General Electric

A large steam turbine is carefully inspected on the testing block before it is finally installed.

THE POWER OF STEAM

How Generated, How Used, How Controlled

IT is now almost two hundred years since James Watt started the steam engine on the course that led to the models that are used today. Since the end of the last century other prime movers have been steadily encroaching upon the supremacy of steam. The latter, however, has retained a good deal of importance in transportation by rail and by sea.

Although it is to Watt that we owe the improvements that gave the steam engine its prominent position, steam had been used as a source of power many years before his time. We have seen in another chapter how Hero produced rotary motion by means of steam more than a hundred years before the birth of Christ. About the middle of the seventeenth century, Edward Somerset, the second Marquis of Worcester, developed the "steam fountain," a device for raising water to the upper part of a house by means of steam. The steam fountain did not make use of a true engine, with cylinder and piston; it was operated by alternately introducing steam into a chamber and then causing the steam to be condensed.

In 1687, the Frenchman Denis Papin published a description of a piston that was driven in a cylinder by the action of steam. At the beginning of the next century, some ingenious Englishmen succeeded in making practical applications of this discovery. Among these pioneers was Thomas Newcomen, who devised an engine in the year 1705. A few years later, probably in 1715, this device was used to pump water from mines. Since seepage was a serious problem in the mines of those days, Newcomen's engine proved to be rather useful, though it was an imperfect mechanism, at best. Steam fountains had served for some time before this to keep mines clear of water, but they were not even as efficient as the cumbersome apparatus of Newcomen.

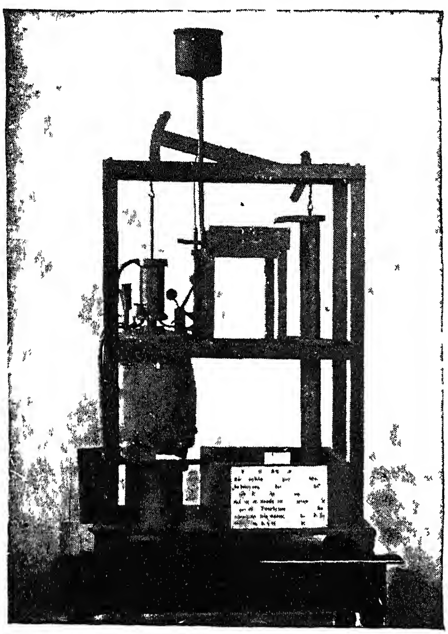
Newcomen's engine used steam from a separate boiler. Steam drove a piston upward in a vertical cylinder. The steam was then condensed by a jet of cold water and the resultant vacuum in the cylinder caused the piston to drop back. At first both the steam and the jet of cold water were brought into play by hand-operated devices.

Newcomen engines were so inefficient that they gave a good deal of trouble. On one occasion one of these engines was sent to the laboratory of the University of Glasgow for repairs. It was turned over to James Watt, who was employed in the university as a maker of mathematical instruments. He made some minor improvements in the engine and got it to run successfully.

Watt now began to work on another type of steam engine and he took out a patent for it in 1769. Watt's engine had a condenser, in which the steam, after driving the piston, returned to the liquid state; it also had a "steam jacket" around the cylinder and a similar arrangement on the cylinder head. These innovations lessened the radiation of heat from the cylinder, thus effecting important savings in fuel. The steam engine had now become a practical source of power. The basic principles of Watt's engine still hold for all steam engines that are not of the turbine type.

Watt's engine was developed in England at a particularly opportune time. The industrial revolution had begun and as a result there was a great demand for coal. Many of the old coal mines had been flooded. The old-model steam pumps were of little use in such cases, since they were too weak to handle anything but minor seepage. Naturally, powerful pumping machinery was soon at a premium. For a long time Watt was kept busy at the task of constructing steam engines for pumping purposes and installing them in mines.

It is interesting to note that about the only work done by steam for many years was the pumping of water. Before Watt's time the power of steam was used only indirectly to pump water. The space occupied by steam is over 1600 times as great as that occupied by the same amount of water, so if steam is inclosed in a tight compartment and then condensed to water, the decrease of volume will form a vacuum, that is, it will cause the pressure to drop below that of the atmosphere, which is a little less than 15 pounds on the square inch. The vacuum in such a compart-



THE MODEL OF NEWCOMEN'S ENGINE THAT INSPIRED JAMES WATT'S INVENTIONS
(Hunterian Museum, Glasgow)

ment, which was in the shape of a cylinder and contained a piston with one side exposed to the atmosphere, was then used to raise a weight by means of the piston. When the weight was allowed to fall again, it did the work of pumping the water.

Watt's first improvement was to close the open end of the cylinder so that steam might be admitted to either side of the piston. This was then driven forward by the rush of steam entering the cylinder, and the engine was made double acting by admitting the steam first to one end and then to the other. He soon found that this was a very wasteful way of doing work and used a great deal of steam. He then discovered another property of this working fluid. He found that if the supply of steam was cut off after it had driven the piston a small part of the way, what was in the cylinder would expand and complete the work. The small loss of power from the early cutting-off of the steam supply was more than made up in the saving of the steam and, therefore, of the coal.

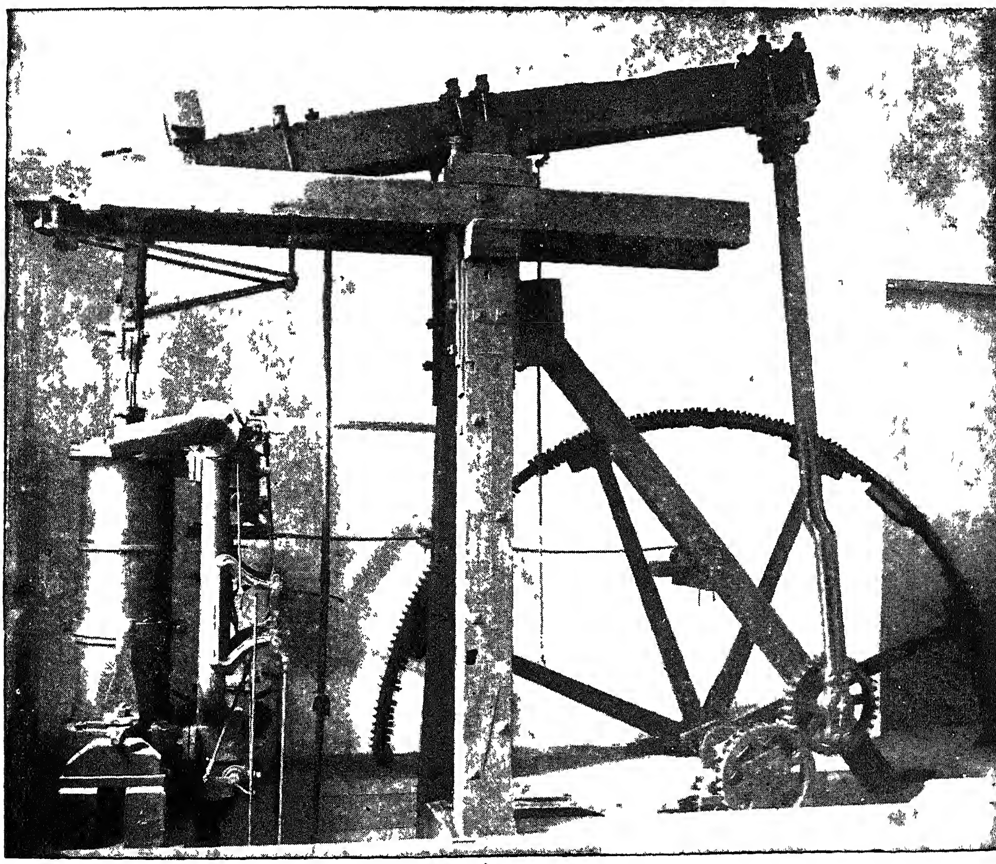
Another of his ideas was the application of the governor, already in use on windmills and water-wheels, to the steam engine. This device enabled him to regulate the speed of the engine automatically. When one considers the variety of new ideas and improvements which Watt applied to the steam engine, his greatness is fully appreciated. His brilliant mind soon saw that his engine could do many things besides pump water and he devised the scheme of crank and connecting rod, now in use, for changing the reciprocating motion into rotation.

Some fifteen years after this perfected engine appeared, Robert Fulton applied the steam engine to navigation, and his little boat made its first trip on the River Seine in France. Soon after one of Watt's engines was used by Fulton to drive the *Clermont* from New York to Albany in 36 hours. The growth of the use of the steam engine from 1769 to the present day has been one of the great factors of civilization. Without it, it is hard to say what the state of the world would be. Such a condition of affairs certainly is not pleasant to contemplate.

Water is such a common substance that few of us stop to realize what a wonderful thing it is. If we heat it sufficiently, it boils or evaporates and becomes a vapor which has useful and wonderful properties. If we inclose it in a tight receptacle and apply heat, it will press against the containing walls and try to escape. The more we heat it the harder will it press in its efforts to get out. These efforts we call "pressure" and their intensity or strength may be measured by a little instrument called a "pressure gauge" on which a hand moving over a dial indicates

the number of pounds pressure on the square inch that the steam is exerting. In Watt's time the pressure used was small, practically that of the atmosphere, but as the materials of construction have improved in strength, the pressure has been increased until now 250 pounds on the square inch is very common, in some few cases 500 and 600 pounds have been used, and engineers are talking of 1000 pounds for a working boiler pressure.

contact with the heat. To make this heating and vaporizing more rapid, tubular boilers were constructed. These were of cylindrical form with a large number of tubes passing through the water space dividing it up and allowing the hot gases from the fire which passed through these tubes to come in contact with a much larger water surface. On the next page (1374) is an illustration showing this present-day form of a horizontal return tubular boiler



JAMES WATT'S STEAM ENGINE

A steam plant for furnishing mechanical power consists of two principal features: a boiler, where the steam is generated, and an engine, where its heat energy is transformed into mechanical work. The first steam boilers resembled the common teakettle, the nose forming a connection with and supplying steam to the engine. The large mass of water in such a boiler was heated and vaporized very slowly, for the outside surface was the only one in actual

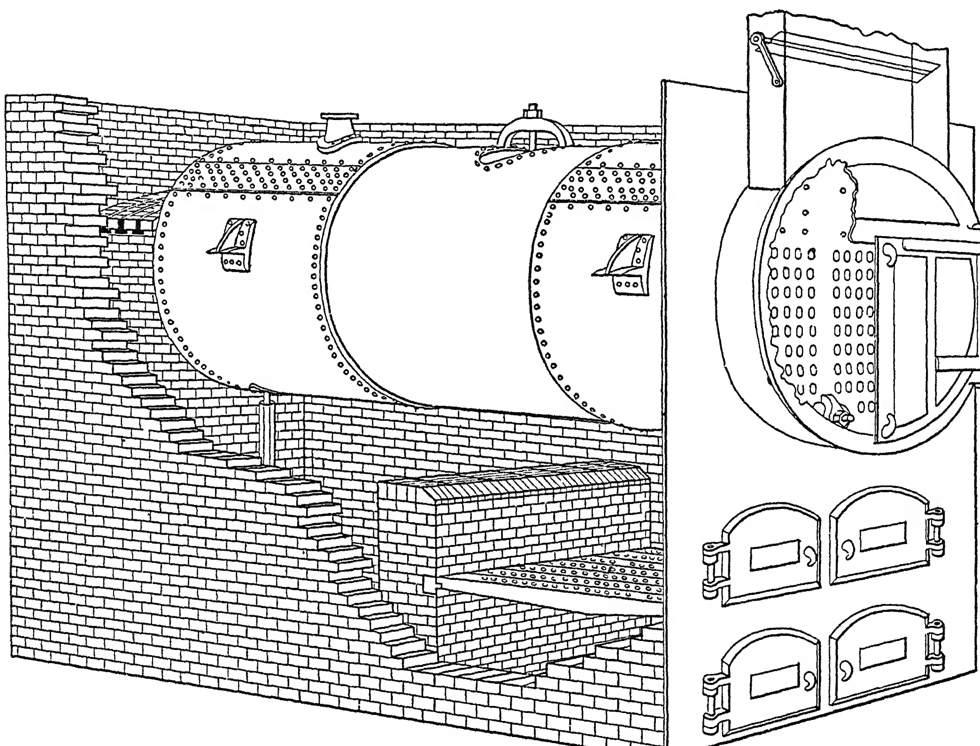
in its setting of brickwork. The hot gases from the fire on the grate pass over the bridge wall, circulate around the lower half of the shell, and, entering the tubes at the rear, pass forward and then through the uptake at the front to the chimney. This boiler is in common use for pressures as high as 150 pounds, especially in mills and factories where the amount of steam used is a fairly constant quantity. It has the disadvantage of making steam slowly and of

not responding quickly to a sudden call for steam. The large body of water and steam inclosed in a single shell makes it very dangerous if for any reason the boiler explodes.

The illustration on page 1375 shows a modern water-tube boiler, so called because the water passes through the tubes and the hot gases surround them instead of as in the boiler described above. Steam is made in the upper half of the steam drum at the top of the boiler. The water is fed into the front end of the drum, the water level being carried as shown. By means of baffles, the hot gases make three passes around the tubes and then flow out at the rear to the uptake. On account of the small size of the drum and the fact that the water is inside of the tubes, high pressures can be safely carried. As has been stated, 250 pounds is not at all uncommon, 500 and 600 pounds have been used in a few cases, and ideas are now being worked out for water-tube boilers carrying 1000 pounds' pressure.

The fact that the water, instead of being altogether in a single shell, is divided among a large number of small sections, not only makes the boiler safer in the event of an explosion, but it is a quicker steamer and it responds easily to a change in the rate of evaporation.

The most important accessories to a steam boiler are the safety valve, the water column, the steam gauge and the mechanism for supplying the boiler with water.

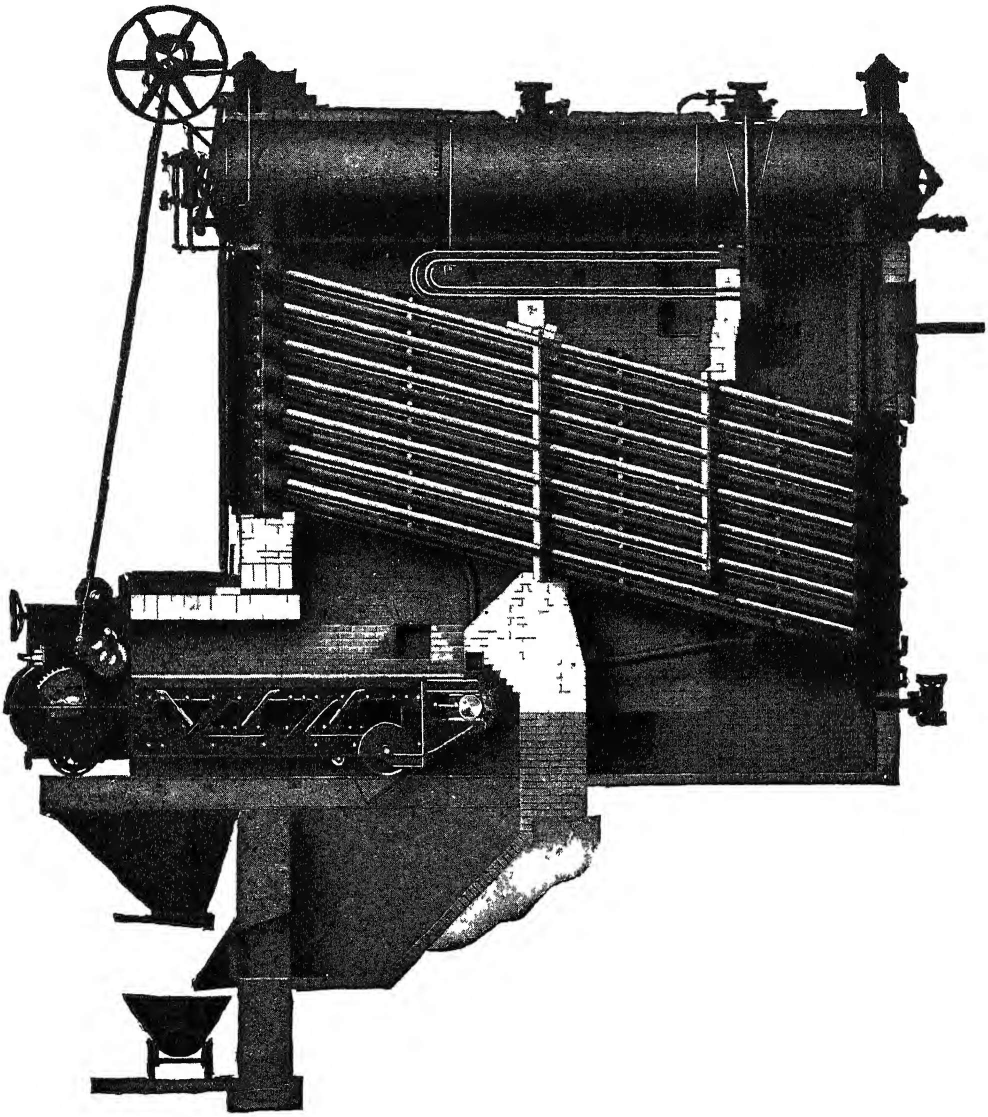


From Peabody & Miller's *Steam Boilers*, John Wiley & Sons

A HORIZONTAL MULTITUBULAR BOILER IN ITS BRICK SETTING

Steam when under control is a most useful servant but if the control is lost, it becomes a terrible master. The steam pressure in a boiler must not be allowed to become too great or the boiler will explode with disastrous results. The safety valve is a means of closing a steam outlet with a plate or cover held down by a spring so adjusted that if the pressure rises a certain amount above the working pressure (usually 5 to 10 pounds) the cover will lift, allowing steam to escape and the pressure to drop three or four pounds be-

low the blowing point, when the valve closes again. There is a maximum pressure on any given boiler beyond which the valve may not be set. This is checked by an insurance or government inspector. The steam gauge shows the pressure in the boiler at any time and its mechanism usually consists of a hollow, flattened, copper tube bent in a circular curve. This is connected by means of gears with the



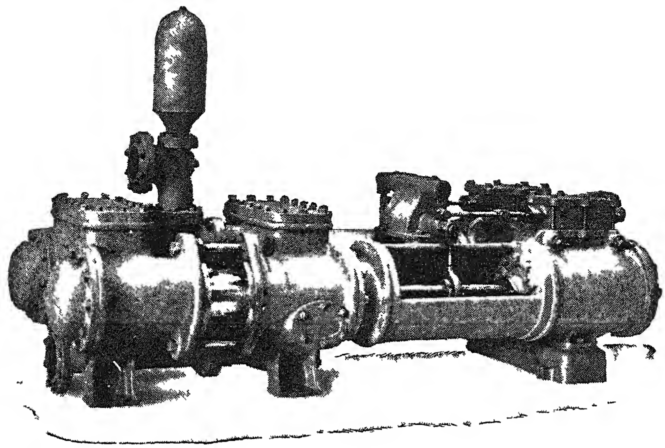
SECTIONAL VIEW OF A BABCOCK & WILCOX WATER-TUBE BOILER IN ITS SETTING

The hot gases circulate around the lower half of the steam drum at the top, and back and forth among the inclined tubes. The safety valve is seen on the top, the steam outlet near the back and the gauge-glass at the front of the drum

so-called "water column" contains a glass tube connected at its upper end with the steam space and at the lower end with the water space. The water level in the boiler should then always be indicated by the height of the water in the glass.

hand over the dial. Pressure within the tube tends to straighten it and this causes the hand to move proportionally to the amount of pressure.

When steam is being taken out of a boiler an equal amount of water must be pumped



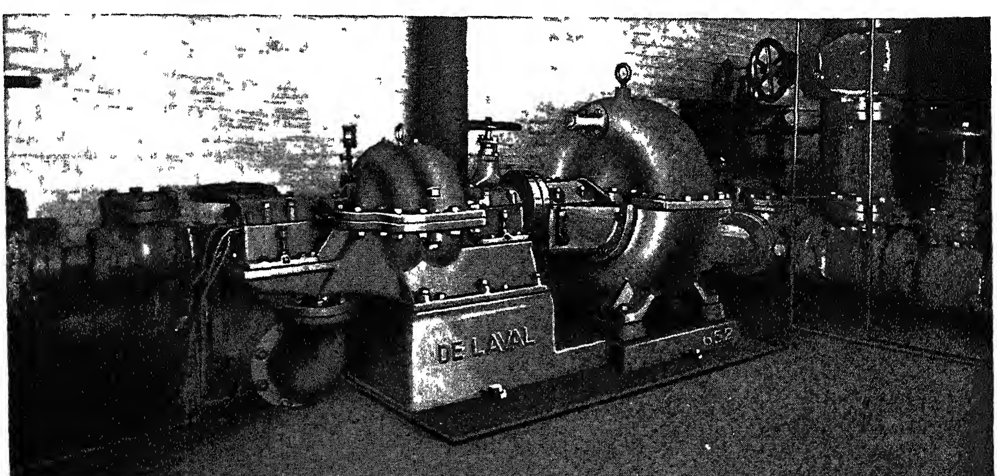
Courtesy Henry R Worthington

DIRECT-ACTING, DUPLEX BOILER-FEED STEAM PUMP

in if the water level is to remain at the same height. Various types of pumps are used for this work. Until recently the direct-acting steam pump, of which an illustration is shown, was almost universally used. Now, however, centrifugal pumps driven by electric motors or small steam turbines are rapidly becoming very popular especially in the larger high-pressure plants.

When air is allowed to pass naturally through the grates of a boiler to aid in the combustion, we say the boiler is working under "natural draft". This requires a very tall chimney to provide a sufficient column of hot air to create the necessary draft. In many cases it has been found more expedient to force the air through the grates by means of a blower or fan. This does away with the tall stack and also allows a better control of the amount of air used. Very often with forced draft a cheaper grade of coal can be burned and a saving made.

The nature of the human race is to try and get as much return as possible for expended effort. In the case of the boiler, the object is to take as much of the heat supplied by the coal as possible and put it into the water in the boiler. The ideal would be to have a complete transference from one to the other but, of course, this is impossible.

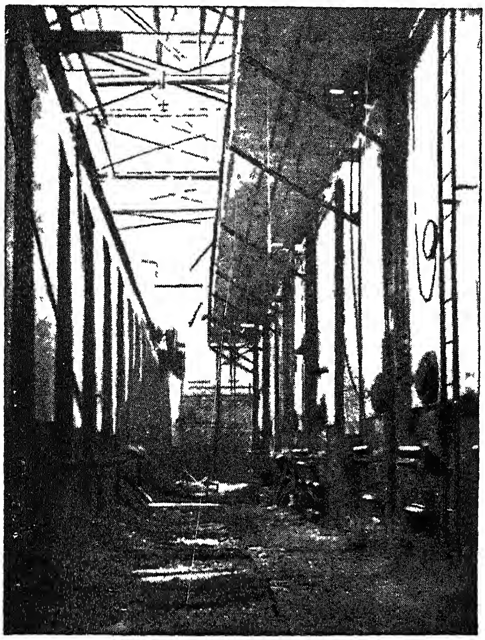


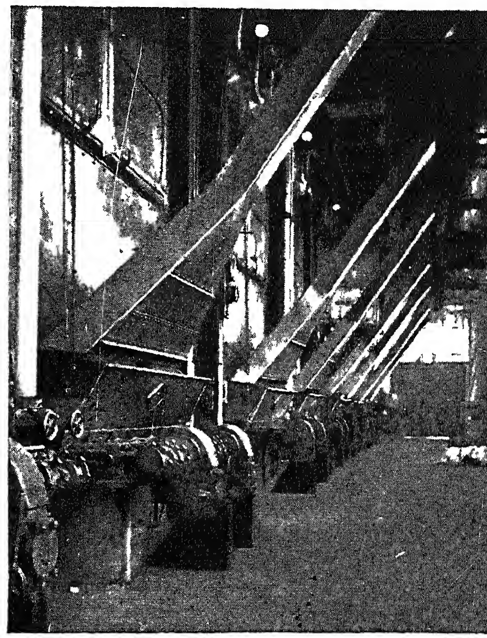
HIGH-SPEED, CENTRIFUGAL, BOILER-FEED PUMP

Such pumps are successfully employed in pumping against the highest boiler pressures now in use. In this particular case the pump is driven by a small steam turbine.

The aim of engineers is and always has been to make the proportion as large as possible. One of the accessories which aids in this process is the feed-water heater. These are of two types, both of which have the same object, namely, to heat the feed-water as much as possible before it is pumped into the boiler. The machine usually termed a "feed-water heater" makes use of the heat in steam that has been exhausted from engines and pumps, and transfers this, or at least the greater part of it, to the feed-water. The other type, known as an "economizer," takes some of the heat from the gases passing from the boiler to the chimney, which heat would otherwise be wasted, and raises the temperature of the water. A saving in coal of about 10 per cent may under proper conditions be made with these devices.

When water has been completely vaporized, the resulting fluid is called "dry saturated steam". If now more heat is added, the steam becomes what is called "superheated," the temperature is increased and, having more heat energy in it, the steam has more power to do work. This superheating may be accomplished either by putting a coil of pipe in the path of the hot gases leaving the boiler and allowing the steam from the boiler to pass through the coil, or by arranging the coil over a separate fire. By this latter method, a much higher degree of superheat, that is, steam of a much higher temperature, may be obtained than with the former. Superheated steam is used chiefly in connection with steam turbines.





Courtesy *Power*

BOILER-ROOM WHERE COAL IS FIRED AND ASHES REMOVED BY HAND

BOILER-ROOM WHERE COAL IS MECHANICALLY STOKED AND ASHES REMOVED

The impossibility of keeping clean the room shown on the left is apparent In that on the right the coal is delivered into the large hoppers above the boilers from which chutes take it to the mechanical stokers shown The ashes are dumped from the bottom of the ash-pit into a car or conveyor on the floor below The contrast between this plant and the other needs no comment.

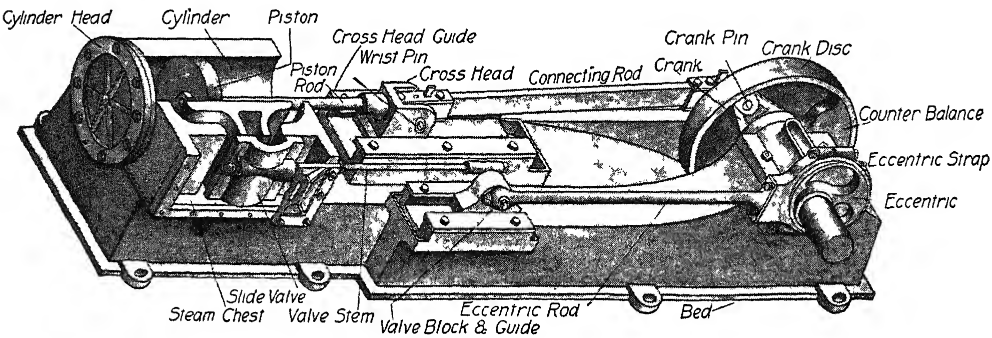
It was not so very many years ago that in all boiler plants the firing was done by hand. The firemen were large and muscular men who had to use considerable physical strength and endurance in their work. The boiler-room was a dusty, dirty place which it was impossible to keep clean. At the present time, although in the smaller plants the same conditions prevail to a certain extent, yet in all boiler plants of any size an entirely different state of affairs exists. The system of hand firing has given way to mechanical stokers which feed the coal automatically and

regularly to the fire. This results in much more uniform conditions and improves the economy of the plant. It particularly helps in making the fire smokeless. In many modern boiler-rooms not a sign of coal is seen and the cleanliness and absence of dust is very marked. The coal may be taken from cars or a coal pile outside the building, raised by a mechanical conveyor to bins over the boilers from which it is discharged through automatic weighing devices into hoppers which deliver directly to the mechanical stokers. The ashes may be dumped into a hopper which discharges into a car on the floor below the boilers and are carried quickly away.

The fireman, instead of being a man of muscle, must now be a man of brains, for his work consists in operating the various mechanical devices which make up this modern boiler plant. A great deal of labor is saved in this way, one man being able to do the work that previously required three or four men. The fireman must be able to get the best possible results from his boilers, and to aid him he has many measuring and recording instruments so that it is possible to tell at any time how much coal and water are being used, whether he is burning his coal to the best advantage, etc. The cry of "efficiency" made necessary by the gradual depletion of our natural resources should be heeded nowhere more than in the boiler-room.

We have seen that in the boiler a part of the energy given up by the coal is transferred to the water which leaves in the form of steam with this heat energy ready for whatever it may be directed to do. It may be used directly for heating in making buildings comfortable in cold weather, in commercial processes where heat is necessary and in various other ways, or it may be sent to a steam engine there to have its heat energy changed into mechanical work.

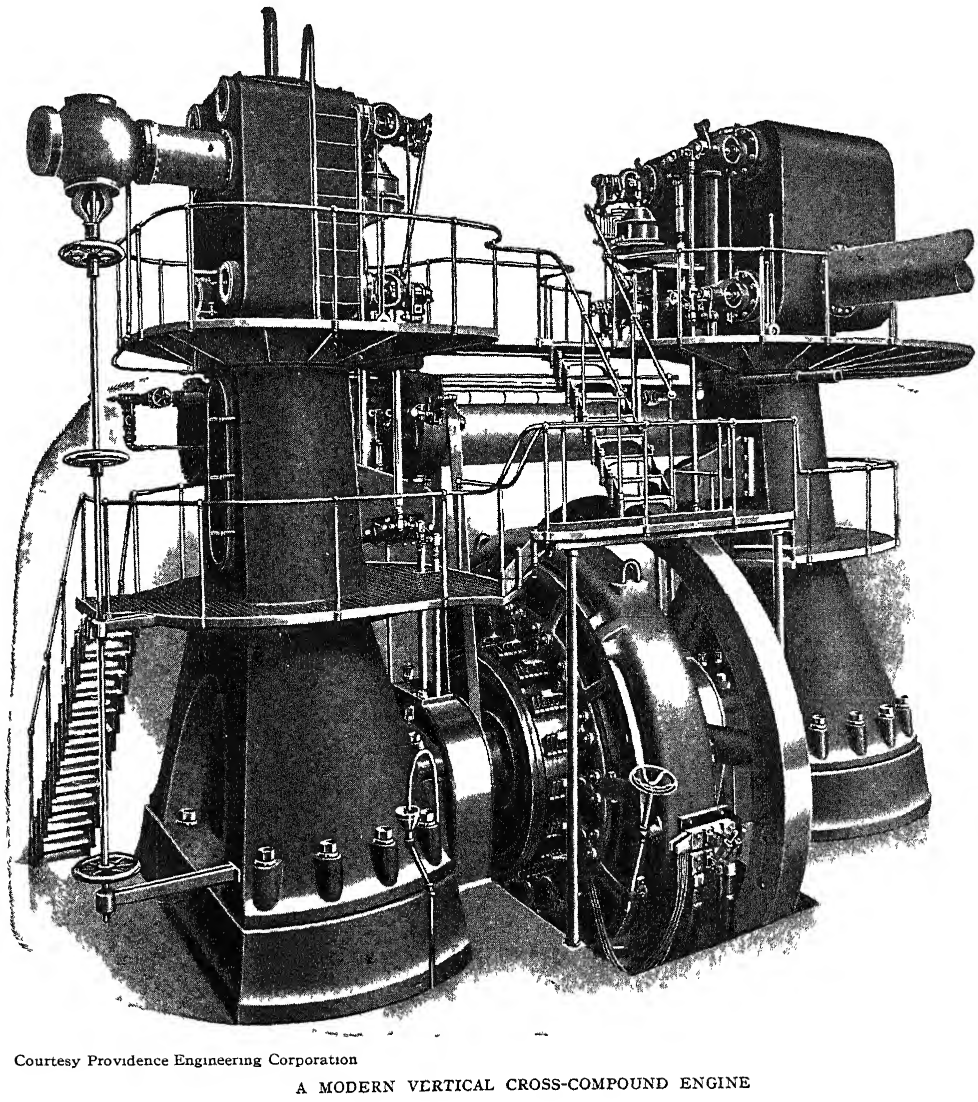
The operations taking place in a simple reciprocating steam engine may be understood by referring to the illustration below. The engine consists of a cylinder, on the side of which is a steam chest, containing three passages or ports, one connecting each end of the cylinder with the nearer part of the steam chest, called steam ports, and the middle one, the exhaust port, forming a connection between the steam chest and the exhaust pipe. The steam pipe from the boiler is connected to the nearer side of this steam chest. In this latter is a slide valve, shaped something like the letter D, which is made to slide back and forth over the three ports. This valve is driven through a valve stem and eccentric rod by an eccentric on the engine shaft. The eccentric does the work of a very small crank and is made necessary because of the small motion of the valve. The valve in the position shown is allowing steam to pass through the left-hand steam port into the cylinder, where it drives the piston toward the right. At the same time it has connected the right-hand steam port with the exhaust passage, and as the piston moves toward the right it pushes that steam which has just finished its work in the cylinder ahead of it out into the exhaust pipe. The motion of the piston is transferred through the piston



From Allen & Bursley's *Heat Engines*, McGraw Hill Book Co

SECTIONAL VIEW OF A SIMPLE STEAM ENGINE

rod, crosshead, connecting rod and crank to the shaft, which is thereby made to rotate. This rotation causes the eccentric to move the valve so that at the proper time the conditions in the cylinder are reversed and steam is admitted to drive



Courtesy Providence Engineering Corporation

A MODERN VERTICAL CROSS-COMPOUND ENGINE

the piston toward the left while that in the other end is forced into the exhaust passage. The useful work of the engine is, of course, taken from the rotating shaft. When the piston is at the extreme ends of its stroke, very little energy can be given it by the steam. To make up for this defect and provide for the smooth running of the engine, a heavy fly-wheel (not shown) is attached to the shaft and by its weight stores up energy which is used at these critical periods As a further aid to smooth running, the valve is made to uncover the steam ports just before the piston reaches the end of its stroke. This forms a cushion and at the same time builds up the steam pressure so that when the piston is ready to start back again, the full boiler pressure is there, ready to exert its full force.

The general principles and main features of engines the same though details vary

The details of the smaller parts of engines, type of valve, arrangement, etc., vary greatly with different makes and conditions of use, but the general principles and main features are the same in all cases.

An important part of an engine not shown in the illustration is the governor. The power which an engine is delivering may vary considerably within a very short space of time. For example, an engine driving an electric generator for lighting may suddenly have large numbers of lights turned on or off. This might vary the horse-power as much as a third or even a half. Now it is very important that the engine always run at the same speed, whatever the load. The governor is a device which allows just this to happen, that is, it keeps the speed of the engine constant under all power conditions.

If an engine exhausts into the atmosphere, the exhausted steam with considerable heat energy in it is thrown away. Now in some cases, as on shipboard, fresh water is very valuable and cannot be wasted, so instead of having the engines exhaust into the atmosphere, they send the steam into a receptacle called a "condenser," where either direct or indirect contact with cold water takes place, condensing the steam which may be then returned to the boiler and used over again. Where the water and steam come into direct contact, the condenser is a jet condenser. Where the contact is indirect, the cold water passing through a large number of small tubes while the steam circulates around them, the condenser is of the surface type. The latter would be found on shipboard where salt water would be used as the cooling medium and the fresh water, condensed from the steam, would be kept separate and could be used over again. When a pump is used to remove the condensed steam and air from the condenser, the pressure in the condenser and therefore in the exhaust of the engine, is reduced below that of the atmosphere. This adds to the power and economy of the engine.

The use of higher pressures brought the introduction of the compound engine

In earlier years, when the steam pressure used did not run over 50 pounds, a single cylinder was all that was necessary to expand the steam down to atmospheric pressure or below and get all the work possible out of it. When higher pressures began to be used, however, it was seen that more power with better economy could be obtained by dividing the expansion between two cylinders. Thus the compound engine appeared. Later, as the pressure was increased still more, another cylinder was added, making the triple expansion engine, mostly used in marine work. In some few cases four cylinders, or a quadruple expansion engine, seemed to be necessary, but in general the added complications of the fourth cylinder more than offset any gain in power and economy.

The general arrangement of a compound engine is shown on the preceding page. As a rule, compound and triple expansion engines exhaust into condensers.

The problem of the design of a large engine is very different from that of a small one. Many new forces and strains appear. One of the most important of these problems is the balancing of the momentum of the moving parts. This, however, can be done with such nicety that an engine developing 10,000 horse-power can be made to run with almost no vibration.

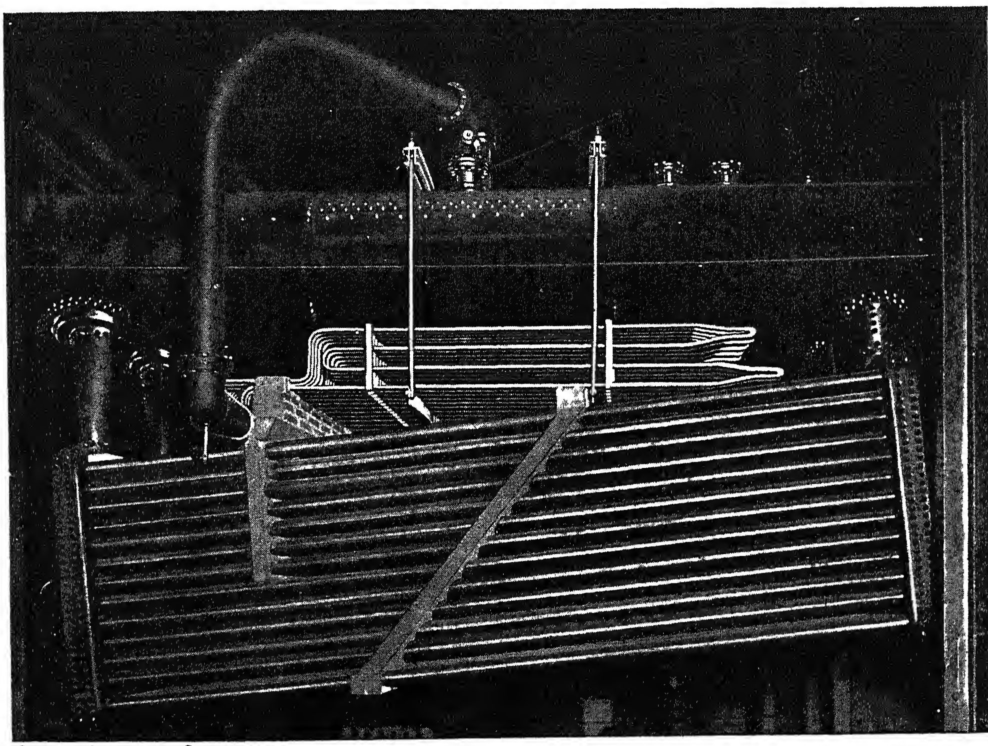
New schemes and new devices, other fuels and other methods

Many new schemes and devices are constantly being tried out in steam plants, some of which have considerable value. In sections of the country where liquid fuel is cheaper than coal, it is being burned in boiler plants with much success. It is also being tried in marine work and gives promise of being used to a greater extent in that field. As the price of coal advances, the cheaper grades are being used in boiler plants, various devices being introduced to keep up the efficiency. One of these is the pulverizing of the fuel and burning it under the boiler with a blast of air. This is proving quite successful.

The general trend of the times is towards higher steam pressures and temperatures, as these not only increase the efficiency of steam engines and turbines from the theoretical point of view but also aid greatly in lessening certain heat losses. At the present time in this country there are fourteen plants in operation using pressures between 300 and 400 pounds, one carrying 475 pounds and one just completed for 600 pounds, while in Germany a plant is operating successfully on a pressure of 800 pounds. Some American engineers are at present at work on a plant designed for 1200 pounds boiler pressure.

There are several reasons why it is wise to add more heat to steam and raise its temperature after the process of vaporization is completed — the process called superheating. Its greatest value is due to the fact that it becomes possible to remove some heat from the steam without causing condensation. As long as the fluid remains in the form of a vapor there is a possibility of doing work with it but as soon as any is condensed into liquid form that part becomes useless for further work.

There are, of course, limits to the amount of superheat that can be used, imposed by such factors as the heat-resisting qualities of the material, difficulties of lubrication, etc. At the present time in this country 725° F. seems to be the highest temperature employed in steam-power plant work and this without regard to the pressure carried. In Europe 800° F. is the stopping point, this excess being due to the fact that there the higher cost of fuel warrants greater expenditures for design and material.



Courtesy Superheater Co

MODERN SUPERHEATER INSTALLED IN LONGITUDINAL DRUM HORIZONTAL WATER TUBE BOILER

Steam is taken from the steam drum of the boiler and enters the end of one of the superheater headers, whence it is distributed through the smaller tubes or units of the superheater located in the hot gases passing through the boiler, and is superheated. The superheated steam is then collected in the second header and passes out at the opposite end to the engine which it is to drive

Practically all power plants having steam turbines as prime movers make use of superheated steam, as it has a considerable effect on the economical operation of these machines. Its use is also becoming general on modern high-powered locomotives.

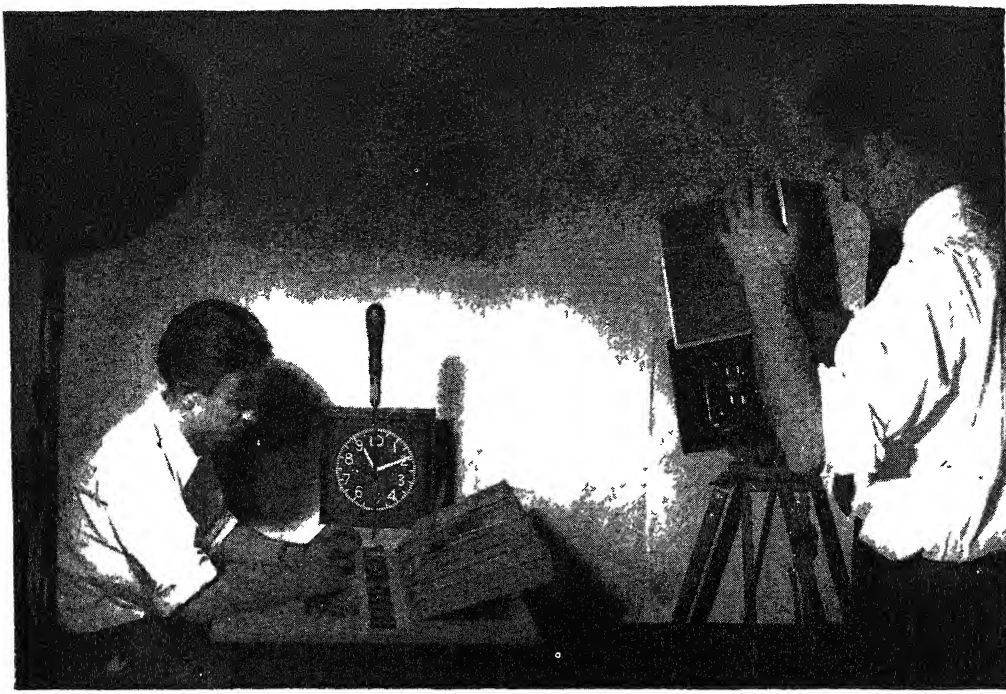


FIG. 5.

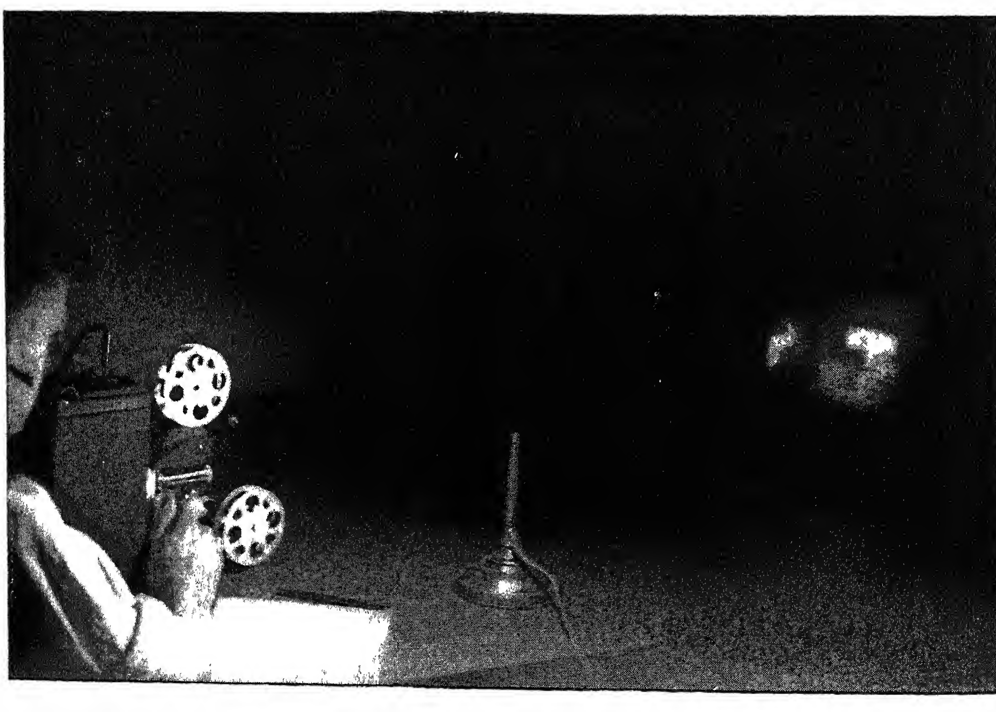


FIG. 6.

MEASURING HUMAN EFFORT

by

DEXTER S. KIMBALL, JR., M.E., M.M.E.

Assistant Professor of Industrial Engineering, Cornell University

HUMAN knowledge of any phenomenon varies widely, extending from pure conjecture to full scientific information. It is customary to divide this range of knowledge into two grand divisions which are variously known as approximate, qualitative, or empirical, and exact, quantitative or scientific. This classification infers or suggests that there is some kind of a dividing line in the degree to which we may be informed concerning any matter. The dividing line is necessarily vague and poorly defined, but the classification serves a useful purpose in accenting the range of our knowledge. To illustrate: every one knows that a loaded plank will bend somewhat, but only those who are scientifically informed as to the laws of bending can say with accuracy how much it will bend. In the first case the knowledge is empirical and in the second case it is scientific. Scientific knowledge is always associated with *measurement* of some kind since measurement is the means of comparing cause and effect. Scientific knowledge also usually connotes *recorded* experience as opposed to *hearsay* or *empirical* knowledge. Thus in the example of the loaded plank quoted above the exact relation between the load, or cause, and the bending, or effect, is known through measuring the results of many experiments and recording them for future use in *predicting* similar phenomena.

It is quite natural to associate scientific experiments and measurements with inanimate, physical objects, but in recent years scientific studies have been extended to human beings in an ever increasing degree, and measurements have long been made of certain physical performances of men in such events as running, rowing, jumping, etc. And in industry crude records had been made of human achievement in the trades and callings. Such recorded performances, however, had reference almost wholly to *total* or *overall* time in judging of these performances.

Near the beginning of this century, however, Fred W. Taylor, the founder of modern industrial efficiency, proposed the idea that industrial operations could be broken up into small elements or units, that the time required to perform these units could be measured and recorded and that, furthermore, these recorded unit times could be used synthetically to predict the total time required for any sequence of operations built up from recorded units or elements. As a consequence, also, he asserted that through the study of unit operations the most efficient sequence could be determined by elimination of useless motions. The methods proposed by Taylor are obviously scientific *in character* and he called his new philosophy "scientific management". Of course his complete plan of management embodied more than time and motion study, but these are among the outstanding features of his philosophy that have survived. Looked upon at first by many as a visionary proposal, time and motion study are found in every progressive industrial plant and while the results of measuring human effort may not be so exact as those obtained from inanimate objects, yet the method is scientific and the results already obtained justify fully Taylor's proposals.

Time and motion study

Time and motion study may be defined as the analysis of the operations of men and the equipment which they use, for the purpose of correlating labor and tools for their most effective application. Contrary to a widespread belief, the application of time study to the measurement of labor has not been established with a sole purpose of setting wage rates. As a matter of fact, we must consider such an application merely as a step toward decidedly more important needs in modern manufacturing or distribution. Furthermcre, if the control of wages were its only use, time study work could be dispensed with, and entail little or no loss to enterprises.

Under our present industrial system it is a well-known fact that with the advent of quantity production and a narrowing margin of unit profits, the need has arisen for very accurate systems of costing products. The old time approximations no longer suffice and a change of five cents in manufacturing or distribution costs is often the difference between success and failure. The cost of a product is made up from three major financial factors, namely, the cost of direct material, the wages for men handling or working the material, and the cost of overhead, or general items such as power, heat, light, taxes, etc. The first and last of these items are purchased as a commodity and hence have a known contribution to the unit cost of the product. A fair return from the cost of the labor must be determined for each product with the same degree of accuracy as the other two divisions. Since labor does not possess many of the characteristics of a commodity a different approach is necessary for this determination.

To meet this need modern time study practice has been evolved. Using it we may first set up the most efficient methods of performing all operations, considering not only the labor as applied, but the material used, and the burden items such as the tooling of the process, economical performance of equipment, economic use of factory space, and the need for safe and healthful practices in manufacturing. Secondly, we are able to measure accurately the cost of all such operations and assign to each product its portion of the total cost. Thirdly, the costs thus made up are indispensable for the purpose of making accurate and hence useful estimates of the cost of manufacturing of products not yet marketed. Fourthly, a satisfactory decision between the quality required and the expense of producing that quality is possible.

It is true that in doing this we have established wage rates. This has become necessary, however, since the costing of a product may only be carried out when the relation between work done and payment for such work become constant. In other words, we realize that the man who can produce twice as much work per hour as another man is twice as valuable to the firm. He may be paid twice the wage of the second man and the firm will still save money by a lighter distribution of the overhead upon the products. We may establish, therefore, a standard payment on units of work.

It is easily conceivable moreover, that the above mentioned men are using different methods and that both are using their respective ability to the extent of only fifty per cent. Therefore, before setting this unit of work for which the standard payment is to be offered, the wasted portion of the work should be eliminated. The remaining portions of the operation may then be analyzed for the most efficient combination and this combination established as a standard. We now have a standard payment upon a standard operation and the labor cost of the product has been established with little chance for variance.

It is important to realize, however, that were we to go to this trouble to establish wage rates only, the cost of the additional labor involved would in many cases offset the saving in wages. A detailed knowledge of the cost of manufacturing is more essential than the reduction of an operator's wage. We cannot hope for duplication of results or standard operations unless all factors contributing to the process are of established efficiency.

The efficient set-up of materials, tools, and labor

Our first analysis, therefore, must be of the existing relation of these factors and the eliminating or rearranging of them for the greatest effectiveness. We must even go to the extreme of making sure that the work is actually necessary. Repeatedly manufacturers have been able to eliminate whole operations or groups of operations with no decrease in the quality of the product.

Material. Assuming that the designer of the product has considered the material used from the "selling" point of view, improvements may often be made from the production point of view. Drawings frequently allow excess material on the unfinished parts, requiring unnecessary work in machining them. Specifications of material are often worded too broadly and material may, therefore, be unusually difficult to work. Cast iron may be harder than necessary, forgings too tough, or wood improperly seasoned.

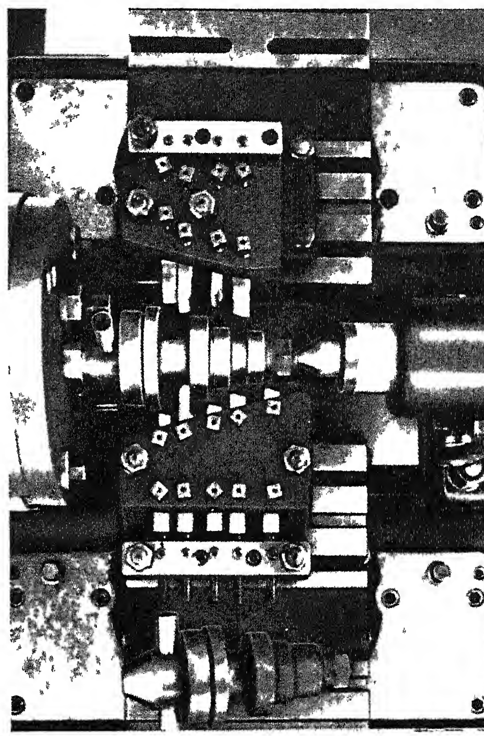
The proper means of handling material must be determined, considering both the labor involved and the expense of installing handling equipment. The proper approach of the material to the equipment and tools must be considered. An expensive machine held up while an operator is handling material is a loss to the manufacturer.

Equipment. It is seldom that two pieces of equipment perform a given job equally well. The machine is always selected for a job considering the accuracy possible, the time required to produce parts of that accuracy, the stress placed upon the machine, the expense of operating the machine and its availability.

Tools. Tools selected to perform a job should be considered first for accuracy, secondly for durability at a satisfactory rate of production and thirdly for initial cost. The proper placing of the tools in the machine in order to utilize its full capacity is desirable. The more that operations can be performed simultaneously and without the aid of the operator, the greater will be the return on the investment and labor.

In Figure 1 we see nine turning tools removing the metal from a gear blank to be used in an automobile transmission. The lathe is semi-automatic and requires the time of an operator only long enough to place a new piece in the machine and remove the completed piece. Hence he may operate two machines at the same time by staggering the times at which loading is required.

Application of the tools. In operating these tools a decision must be made con-



Courtesy of The Lodge & Shipley Machine Tool Co.

FIG. 1.

cerning the rate at which metal is to be removed by any individual tool. This involves a knowledge of proper speeds of tools and work, the speeds of any relative movements between them, the depth of the cut of the tool, the means of cooling the tool, and certain other factors. It will be found that for any given tool set-up there will be a definite relation between the rate at which the material may be removed and the net production over a span of time.

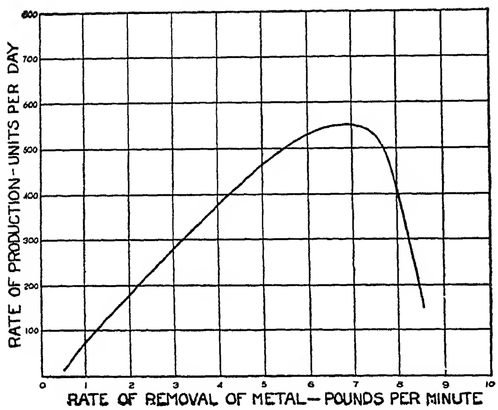


FIG 2.

Such a relation is illustrated by the curve in Figure 2. Here we notice that as the rate of removal is first increased from zero to two pounds per minute the production is slightly more than proportional since under very light cuts there is a tendency for tools to rub rather than cut, thus causing excess regrinding. This condition eliminated, the curve tends to follow a direct proportion until we commence to load the tools so heavily that excessive regrinding is again necessary. Finally a point is reached where the cost of grinding and the cost of tool replacement overbalances the gains in production and the curve drops off. This maximum point, then, is that towards which a good study of these factors should lead us.

Analyzing the motions of an operator

It is first necessary to break any operation which is to be studied into its smallest measurable divisions. This affords, first, a means of locating all wasted or inefficient motions. Secondly, it presents a better means of comparison of like units, since repetition of smaller movements are more frequent. The term "element" has commonly been applied to this unit. A series of elements or in some cases a single element may compose an "operation". This has the characteristics of a more definite accomplishment than the element. A "cycle" is any sequence of elements which repeat themselves in that sequence periodically. To illustrate, an operator may be drilling three holes in each of a large number of similar pieces using a drilling machine. The time from the point of touching a piece in picking it out of a container to the point of picking up the next piece is a cycle. The time to carry the piece from the container to the table of the machine is an element. An operation would be considered as the lowering of the drill to the work, the cutting of the metal, and the raising of the drill after cutting.

For the sake of uniformity in treatment, the limits of all elements must be sharply defined. It is difficult to repeat consistently measurements taken while the hand or portion of the machine is in motion. More accuracy may be obtained by choosing elements between points of contact, or release of the hand to the machine or part, or of the tool to the part. Frequently the noise of some such contact is sufficient to serve as a limit of time.

Certain improvements in operations and elements are often immediately obvious to the man making the study and corrections may be made before the detailed analysis is started. After this is done a record is usually made of the elements and their sequence, in the job as being performed. Several methods are used, each of a particular advantage in their own field. Perhaps the simplest and least expensive method is the "stop watch" method in which the movements and their respective times are written up at the scene of the job upon a form or record sheet. A more recent method consists in photographing the cycle upon a small moving picture film, the analysis being made after the development of the film. A third method, less widely used, is the Gilbreth Cyclograph, which consists of locating small lights upon that part of the body or machine requiring analysis. This light is registered upon a photographic plate over a period of time in a manner such that the path of the light only is recorded.

The stop watch method. This method requires the use of a stop watch so divided that one passage of the hand around the dial takes one minute and divides that minute into a hundred parts. A smaller

dial indicates the full minutes. A board is frequently used which serves to support the record sheet required and the stop watch near the upper edge. In this way the travel of the eye is limited from the operation to the watch and to the sheet, thus avoiding errors. Figure 3 shows a study being made of an operation upon a small lathe.

The form used for recording the data varies with different applications, Figure 4 being a commonly used type. Some forms record analysis of the movements of both hands, although this is less suited to this type of study. The detail into which the study must be broken will depend upon the possible economies to be gained.

A sufficient number of readings are made of complete cycles to give average results including any peculiarities of the operator or the set-up, which may exist and which should not be overlooked. Frequently an "overall" reading is made as a check upon the total of the elemental times. Thus in Figure 4 the cycle consists of seven operations and this cycle has been timed nine times, the period required to perform each operation being timed and recorded. The average of nine readings is shown at the bottom of the record sheet. In making this study, the stop watch was started from zero and ran continuously up to 10.57 seconds which was the last reading. The successive timing of each operation was recorded on the chart under the preceding reading, thus bringing the elapsed time of each operation in a vertical column.

This method of study has the advantage of requiring less elaborate and expensive equipment, of being more readily applied in the shop, and of being more satisfactory upon jobs which are not to be performed with unusual frequency. It does not give the detail that other methods may give, and the record is not as complete as a filmed record.

Photographic Methods. This required the use of a small motion picture camera usually equipped for 16 millimeter film, and the necessary lights and electrical apparatus to take pictures in partially darkened or congested positions. For the purpose of analyzing the photographic record, a small projector for the same film is necessary. This projector is so equipped that it may be stopped for every picture or "frame" on the film to permit analysis of that movement and checking of the elapsed time. In Figures 5 and 6 we see a study being photographed and analyzed by this method.

The elapsed time of the elements studied may be measured in two ways. If the camera is electrically driven by a synchronous or constant speed motor, the number of frames or exposures per minute is positively known and a counting of the

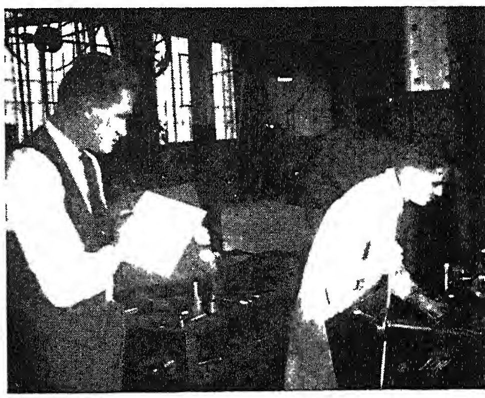


FIG. 3.

frames in the analysis will give the time in any case. This has the disadvantage that if the film is broken and repaired there is no longer a record of the elapsed time. The other method consists in placing a large clock within the range of the camera when the study is made, placed so as not to obstruct the view of the operations. This clock has a fast moving hand and a slow moving hand which permit reading to divisions of one thousandth of a minute. Obviously, the time for any element may then be determined while analyzing the film by subtracting the initial time from the final time as projected upon a screen. Figure 5 illustrates this method of timing.

The data may now be copied from the film upon an analysis sheet which may be of the same form as the stop watch sheet (Fig. 4), or one may go into any desired detail of the action of the different members of the body. Some studies such as

TIME STUDY OBSERVATION SHEET

OPERATION *Drill holes in bracket* MATERIAL *Cast iron* DATE *11/2/32*

MACHINE *Avey Drill Press* TOOLS *Jig # A-45, 1/4" Drill, 5/16" Drill*

	1		2		3		4		5		6		7		8	
	Clamp piece in jig		Drill #1 1/4" hole		Index jig		Drill #2 1/4" hole		Index jig		Drill 5/16" hole		Remove piece from jig			
FEED			Hand				Hand				Hand					
SPEED			532 R.P.M.				532 R.P.M.				532 R.P.M.					
R = WATCH READING T = ELAPSED TIME	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T
	0.19	.19	0.46	.27	0.52	.06	0.77	.25	0.85	.08	1.20	.35	1.28	.08		
	1.51	.23	1.70	.19	1.75	.05	1.97	.22	2.07	.10	2.40	.33	2.50	.10		
	2.67	.17	2.85	.18	2.89	.04	3.08	.19	3.14	.06	3.47	.33	3.55	.08		
	3.84	.29	4.03	.19	4.08	.05	4.25	.17	4.32	.07	4.63	.31	4.73	.10		
	4.93	.20	5.16	.23	5.22	.06	5.45	.23	5.50	.05	5.81	.31	5.94	.13		
	6.21	.27	6.42	.21	6.49	.07	6.65	.16	6.73	.08	7.02	.29	7.10	.08		
	7.28	.18	7.48	.20	7.54	.06	7.69	.15	7.77	.08	8.08	.31	8.18	.10		
	8.38	.20	8.56	.18	8.63	.07	8.83	.20	8.90	.07	9.24	.34	9.32	.08		
	9.51	.19	9.76	.25	9.81	.05	10.04	.23	10.14	.10	10.47	.33	10.57	.10		
AVERAGE	.22		.22		.06		.20		.08		.32		.09			

REMARKS

OBSERVED BY *R. L. H.*

FIG. 4.

those which have been made upon the action of the hands typewriting, consider each finger individually. Here again the economy of the procedure must be considered.

The photographic method has the advantages of recording more detail of the operation permanently, and with a greater degree of accuracy than the stop watch method. It is obviously less universal in its use since considerable distraction is unavoidable in setting up equipment in the shop. The cost is considerably higher than the stop watch method and therefore its use is restricted for the most part to studies where the operations are repeated and

in illustrating to operators and supervisors of plants the typical improvements which are possible in job set-ups and sequence of motions. The improvements are to be made by these men, using no equipment but their good judgement.

Gilbreth Cyclograph. Where further analysis of the paths of motion has been desirable, F. B. and L. M. Gilbreth have developed the cyclograph. A small light is attached to any part of the body where the travel is to be measured. The lights are caused to blink at a uniform rate and are so wired through the timing device that the light gradually diminishes in intensity towards the end of each flash. In this way the path may be photographed over a short period of time and the path and direction of the motion recorded. The time is determined from the number of breaks in the line on the photographic plate.

The field of this method is, of course, restricted, but it is of use in teaching some of the principles of motion economy.

Improving the cycle

It is now necessary to consider each element upon the data sheet and decide whether it is useless, satisfactory, or may be improved upon. First both hands should be productively occupied as large a percentage of the time as possible. Moving the hands around empty, permitting them to remain idle, or using one hand to support work upon which the other hand is operating usually indicate an uneven distribution of the elements between hands or improper use of such supplementary equipment as "jigs" or "fixtures". Secondly, it has been found that a greater efficiency may be attained when the motion of the hands and arms are simultaneous and symmetrical. Thirdly, unnecessary travel of parts of the body should be eliminated by the better positioning of material, tools, or operating position. Lastly, work which endangers the operator must be eliminated. Such work may be of immediate danger, as found in punch press operations, or of an indirect nature, as in those requiring heavy lifting, overreaching, or inhaling poisonous fumes.

From the standpoint of the machine and tools, certain elements may be found to be unnecessarily long due to poor design, set-up, or application. Frequently such losses are apparent only after a detailed motion analysis has been made. As a further check upon such analysis a comparison should be made between like elements in the same study or like elements in different studies. Similar elements in other studies frequently give a satisfactory check.

The cycle being reduced to only the required elements, the next step is the arrangement of these into the best sequence, so dividing the work between the hands that the net result will be most effective. The relation of one element to its adjoining element usually has some effect upon the time which must be allotted to it. A good sequence will frequently eliminate some elements.

Where possible a trial of the new cycle is advisable to check the times allowed and to make further changes which may be required. It is well to remember that the best method is usually the safest and easiest for the worker. The Gilbreths, who have done much pioneer work in motion study, have stressed the idea that for any given set of operations there is one sequence of these operations that is the "one best way". A practical example may make this theory plainer.

A motion study of a simple assembly operation

The reader is familiar with the electric plug which is commonly used to connect an electric wire to such household fixtures as the electric iron, toaster, or coffee pot. This plug is made up of two hard rubber or composition sheathes which hold between them two copper or brass "jacks" or terminals, and a spring which extends from the end of the assembly to support the wire from the source of current. The two halves of the plug are held together by a pair of machine screws and nuts.

The method of assembly of this unit presents a typical problem in time and motion study. The reader may check the time it would require him to perform this simple operation with the use of only a

small screw driver. Using good judgement in positioning the material and the most efficient use of the hands possible, the assembly may be done in slightly less than half a minute.

Figure 7 illustrates a motion study being made of one simple set-up. The material is located in containers on an arc in front of the operator. This gives the minimum

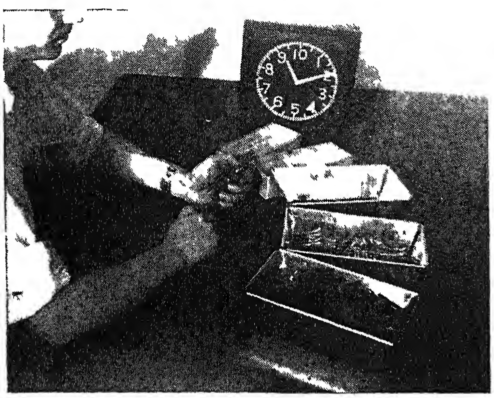


FIG. 7.

distance to travel for the parts. Filming this operation with the use of a "micro-motion" clock in the background the analysis as shown in Figure 8 was made up. Notice that in the elements of the left hand a total of .184 minutes is spent "holding" the piece, .037 minutes "waiting" and .012 minutes returning the hand to empty position. In the right hand .114 minutes is used "holding", and .034 minutes "waiting". This makes a total of .381 minutes of wasted time out of the .990 minutes used by both hands. Hence we will eliminate these elements and supply the necessary holding devices and material handling devices to replace them.

Checking the second requirement as outlined upon page 40 we can see at a glance that the movements are not symmetrical. The left hand grasps the two jacks while the right hand grasps a spring. The left hand grasps a nut while the right grasps a screw. This unbalancing effect is undesirable as an increased expenditure of both physical and mental effort is necessary. The exaggerated effect may be noticed while supporting a heavy suitcase in one hand and a light one in the other. The need for symmetry may be observed by walking or running with both arms swinging forward and backward together.

To avoid this condition one of the most common procedures is the duplication of all effort in both hands and arms. Hence in arranging a better cycle we will attempt to have each hand assemble a complete plug and complete two plugs per cycle.

In checking the third requirement, of reducing the travel of the hands and arms, one of the first faults we see is the return of the left hand after disposing of the finished piece. We will attempt to avoid this by arranging operations to be performed upon this return trip. We can also see that the containers are high and as the supply becomes lower, a greater reach is required to grasp those parts in the back of the container. To avoid this we will arrange sloping containers or hoppers which always permit the parts to slide by gravity towards the front. The level of the front of the hoppers may be reduced thus avoiding the reach over the edge.

In looking over the column of elapsed times the requirements for, screwing the units together are unusually large. A rachet and spiral drive screw-driver may reduce this time. Furthermore, this screw-

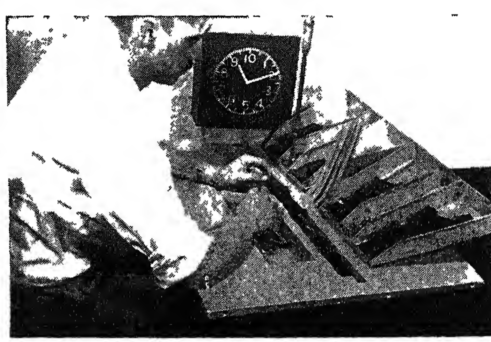


FIG. 9.

driver may be hung from a counter weight so that it is always "pre-positioned" at the point it is to be used.

With all these possibilities in mind we can make up an inexpensive fixture as illustrated in Figure 9. In this set-up we have located a slot across the table in front of the operator. This slot is slightly deeper than one half of the assembly, thus per-

CLOCK READING	ELAPSED TIME	OPERATION Assemble Electric Plug DATE DEPT. LEFT HAND MOVEMENTS	CLOCK READING	ELAPSED TIME	MOTION ANALYSIS SHEET RIGHT HAND MOVEMENTS
620		Discard finished piece	620		Drop screw driver
632	012	Return hand	632	.012	Grasp 2 compositions
669	037	Wait	669	.037	Place 2 compositions
685	016	Arrange compositions	685	016	Arrange compositions
716	031	Grasp 2 jacks	716	.031	Grasp spring
764	048	Place 2 jacks	730	.014	Place spring
		" " "	764	.034	Wait
786	022	Grasp one nut	786	.022	Grasp screw
809	023	Place one nut	809	.023	Hold
834	025	Assemble compositions	834	.025	Hold
846	012	Raise assembly	846	.012	Hold
878	032	Hold	878	.032	Place screw
938	.060	Hold	938	.060	Screw
951	013	Drop assembly	951	.013	Grasp screw
973	.022	Grasp nut	973	.022	Hold
996	023	Place nut	996	.023	Hold
008	012	Raise assembly	008	.012	Hold
040	.032	Hold	040	.032	Place screw
100	.060	Hold	100	.060	Screw
115	.015	Discard finished piece	115	.015	Drop screw driver
		Total time per piece		.495	

FIG. 8.

mitting both halves of the sheath to be properly guided, without the use of the extra hand, while screwing them together. Since the nuts must be applied from underneath if the screws are dropped in from above, they are fed down four supply chutes from behind the slot and forced up into the composition by a foot-operated plunger, till they are in position to start on the threads of the screws.

CLOCK READING	ELAPSED TIME	OPERATION Assemble Electric Plug DATE DEPT. LEFT HAND MOVEMENTS	CLOCK READING	ELAPSED TIME	MOTION ANALYSIS SHEET RIGHT HAND MOVEMENTS
400		Discard finished piece	400		Discard finished piece
420	020	Grasp one composition	420	.020	Grasp one composition
432	.012	Place composition	432	.012	Place composition
457	.025	Grasp 2 jacks	457	.025	Grasp 2 jacks
505	.048	Place jacks	505	.048	Place jacks
525	.020	Grasp one spring	525	.020	Grasp one spring
537	.012	Place spring	537	.012	Place spring
557	.020	Grasp one composition	557	.020	Grasp one composition
567	.010	Place composition	567	.010	Place composition
608	.041	Grasp 2 screws	608	.041	Grasp 2 screws
661	.053	Place screws	661	.053	Place screws
684	.023	Grasp screwdriver	684	.023	Grasp screw driver
739	.055	Set up 4 screws	739	.055	Set up 4 screws
752	.013	Grasp assembly	752	.013	Grasp assembly
770	.018	Discard finished piece	770	.018	Discard finished piece
		Total time per 2 pieces		.370	
		time per one piece		.185	

FIG. 10.

Two assemblies are operated upon at once, each hand performing the same task simultaneously. The two assemblies are completed at that point in the middle where the nuts are fed in, but there are three other assemblies at either side, as illustrated, which are being worked upon and fed in from the outer part of the table. In this way each piece added must be carried a minimum distance.

The procedure then is as illustrated by the motion analysis in Figure 10. The finished assemblies are discarded at the side of the table and as the hands start back towards the center of the table a bottom composition sheath is placed in the slot on each side and the three remaining ones are forced inward. As the hands pass towards the center, the jacks, springs, top compositions, and screws are added. A spiral screw-driver suspended directly over the center is then used to fasten the parts together, and the cycle is repeated.

Notice the absence of wasted time in this set-up and the rapidity of operations compared with the original procedure. We are now able to assemble the two pieces in .370 minutes or only .185 minutes per piece. Furthermore, the effort expended is considerably reduced with the new set-up.

Setting the standard time

The time which we have so far determined has been designated as the "base time". A man cannot maintain it over a long period since there are certain interruptions, tools to be ground, materials to be secured, or natural fatiguing effects for which we must make allowance. For this reason a percentage of the base time is added to give the "standard" time. This percentage varies with the type of work performed and with the policy of the firm. The common range is between five and twenty per cent.

The results are now posted upon a standard time sheet or card, giving a complete record of the set-up and references to the original data. The record is used first by the cost department in determining the cost of the present product. It may be pointed out that an operator may not perform the job in the time assigned. This is true, but where a large number of such jobs are being performed in the plant the average efficiency is known from the time cards turned in and any average deviation of the actual times from the standard may be taken into account with but slight error in the net results.

Time study records are used secondly for making close estimates upon work which has not yet been started. For this purpose well-kept files are necessary of all studies made in the shop, with suitable indexing features. In some cases standard rate tables are made up for common elements and operations where considerable data have been accumulated. Using such data it is also common practice to make up studies of processes being performed in a shop at the time, without going to the scene of the operation. These studies have been termed "synthetic" time studies and in many cases are more desirable than original studies. There is not only less chance for human error but less opportunity for complaint on the part of the operators due to the standardized features of the method. In connection with this work complete records of tooling, feeds, speeds, depths of cut, material, and other variables are essential.

The third use of these studies is in the setting of wage rates. If operators are to be paid in some proportion to their output, the wage for a standard hour of work may be so set that the average worker makes a good income, but the less efficient man still makes a "living" wage. Various bonus plans have been adopted in so doing, most of them representing a company policy.

Cases frequently arise where a worker is outstandingly fast upon a certain operation and he performs the work in very much less time than the rate set. Good time study practice indicates that where this is the case, the standard time should not be reduced unless the operation has been altered in some detail. Such a move immediately indicates to the workman that rates are set only as a control of wages, and results in a reduced efficiency. It should be understood that the burden being carried by a plant is often two or three times the cost of the direct labor on the job. Hence where an operator is unusually fast, he may still be paid in direct proportion to his output, and the firm will be making even more money since the more nearly fixed burden cost is distributed over a larger number of finished parts. Many managements have not appreciated this fact, however, and have employed poor practices in changing wage rates.

This has often lowered the effort of such large groups of men that a standard of comparison is no longer available between operators, and the net return on wages expended is definitely reduced.

It is for this reason that the writer has stated that where time study is employed for setting rates alone, the idea of a fair value for labor is often lost and the manufacturer is the eventual loser. Where the analysis is made for the purpose of determining unit costs of production and a standard scale of labor costs set and maintained, there is less risk of hidden variables in the costs. The real gain comes in knowing ahead of the production date the exact difference between the cost of producing the material and the price it is sold for.

Certain further precautions must be exercised by the management to maintain standard times. All shop conditions must remain constant as far as possible. The times for material deliveries, ringing in time clocks, and tool grinding, heat, light, and supervision all must be uniform to insure standard times. Instructions to the workman, both oral or written must be supplied at the time of repeating any job, if the time is to be duplicated.

Above all the workman must understand the principles and uses of time study work, or many false and harmful impressions will circulate. Their full confidence and coöperation will be of material assistance in securing good results. Where such confidence exists between management and men, remarkable savings in time can often be made.

The example shown in the foregoing has been taken from a manufacturing operation, the field where Taylor's work originated, and in which it has naturally found its greatest application. But it should be remembered that the idea is basic and can be applied to any field of activity where manual and mental operations are used. One of the finest applications is found in college rowing and it has been successfully applied to domestic work. The field of application is unlimited.

THE ROMANCE OF RUBBER

A Substance that Enters into Our Common Necessities, Daily Comforts, and Special Luxuries

HOW THE WORLD'S SUPPLY HAS INCREASED

THE romantic past of rubber and the still more romantic present show how man's great chemical and mechanical genius has taken this product of nature and varied its use until there seems no limit to the things it can do for us. The story of rubber is a true story of adventure, a story that continues every day, a story that affects all of us.

Early history of rubber

Rubber is old—no one knows how old. Records tell of a fossil of a rubber-like plant belonging to the Pliocene period some three million years ago. Rubber relics found among the Mayan ruins at Chichen Itza, Yucatan, and British Honduras lead many scientists to believe that crude rubber was used in the eleventh century.

Christopher Columbus first told the civilized world about rubber. On his second voyage of discovery, according to Spanish and Portuguese historians, he saw natives playing games with "bouncing" balls. Columbus could not believe his eyes and was still more astonished to hear that the bouncing balls were made from the hardened juice of trees.

In 1520 Emperor Montezuma entertained Cortez and his soldiers in Mexico City with a game played with rubber balls. A prominent Spanish historian described it: "The ball was made of the gum of a tree that grows in hot countries, which having holes made in it distills great white drops that soon harden, and being worked and molded together turn as black as pitch. The balls made thereof, though hard and heavy to the hand, did bound and fly as well as our footballs." That was probably the beginning of all our modern rubber ball sports.

Almost a century later, in the early years of Virginia's colonization, Juan de Torquemada wrote of the Mexican Indians making shoes, headgear, clothing, and other watertight articles from the gum of a tree: "This tree yields a white milky substance. To obtain it, the tree is wounded with an ax or cutlass, and from these wounds the liquid drops. The natives collect it in round vessels; it settles in round balls. They used to play with these balls, striking them against the ground and making them raise to a great height." He also wrote: "Our men used it to wax cloaks against rain.... which are some good to resist water, but not the sun, because its heat and rays melt it." Little did he realize it would take man over 200 years to discover how to keep rubber from melting under heat.

In 1736 the French Academy of Science sent Charles de la Condamine, a French scientist, to South America to find out more about the earth's shape and size. On a long, dangerous trip across the country, he became excited over the gummy substance used by the Indians to make waterproof clothing, shoes, battle shields, and bulb syringes or bottles, and stirred up interest at home over the milk from the "weeping tree."

In 1770, while the American Revolution drew steadily nearer, Joseph Priestley, English chemist and discoverer of

oxygen, called attention in England to: "a substance excellently adapted to the purpose of wiping from paper the marks of a black lead pencil. It must, therefore, be of singular use to those who do practice much drawing." This was probably the earliest commercial use of rubber, still important to us, though the rubber looks far different today. From this use, the gummy substance received its English name—rubber. In those days a cubical piece of about half an inch cost three shillings.

An Englishman, Samuel Peal, took out the first known rubber patent in 1791: "a method of rendering perfectly waterproof of all kinds of leather, cotton, linen, and woolen cloths." A few years later, the first shipment of crude rubber arrived in the United States, in the form of rubber bottles. It came from Brazil.

One pair of rubber shoes came to the United States in 1820. They were gilded and the shape of Chinese shoes. The same year the first English rubber factory was established by Thomas Hancock, the man who invented and patented many new uses for rubber, developed an astonishing machine to soften crude rubber, and produced in 1846 a solid rubber tire for horse-drawn carriages, used by Queen Victoria.

In 1823, the year the Monroe Doctrine was placed before the world, Boston, Mass. received 500 pairs of rubber shoes from Brazil. There were no rights or lefts, and no sizes. The thick rubber shoes just stretched over leather shoes, became stiff with cold, sticky with heat. In England, Charles Mackintosh patented a process for making double-texture waterproof coats, the start of our modern raincoats. Soon they were called mackintoshes. They kept out wet, but when it was cold they were so hard they could stand alone; when it was hot they were so soft they oozed. Woe to the man who went near the fire in mackintosh and rubber shoes!

In 1833, while Andrew Jackson was President, the first rubber manufacturing plant in the United States started in Roxbury, Mass. Other plants soon sprang up, making boots, shoes, waterproof clothing, life preservers, mail bags, and rubber hose. There was great speculation in rubber. But the boom soon burst because in the United States, as in all countries where men worked on rubber, people could not trust it. It was not dependable. It was as fickle as the weather; in fact it changed with the weather.

Rubber had now been known in Europe and North America over 300 years but it seemed to have no future. Americans considered it a failure. Intelligent minds had worked on its problems, much money had backed it but no way had been found to make rubber last and be practical for our use.

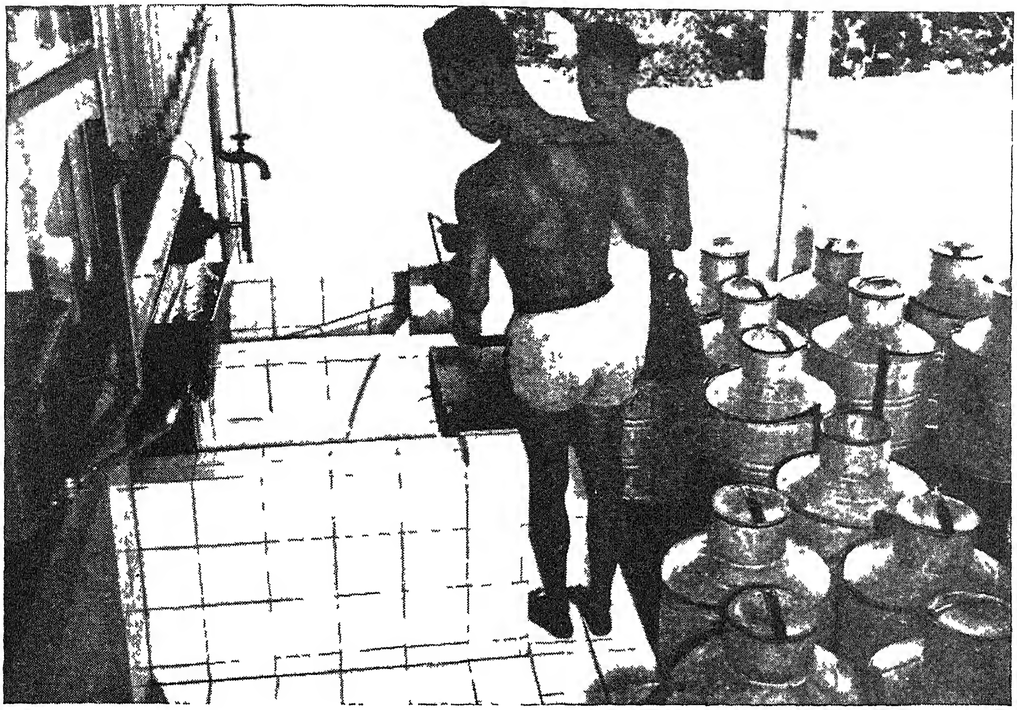
Work of Charles Goodyear

Then Charles Goodyear became interested in the baffling problem of rubber, devoted years to experimenting with it, and finally discovered the one fundamental process that makes rubber our servant today. The son of an inventor, he, too, had an inventive mind and stepped into a store in New York City to buy a life preserver for use in connection with one of his inventions. A year later, when he went back to the same store, the merchant had almost $20,000 tied up in rubber goods that had become worthless because of summer heat. The unsolved problem challenged Goodyear.

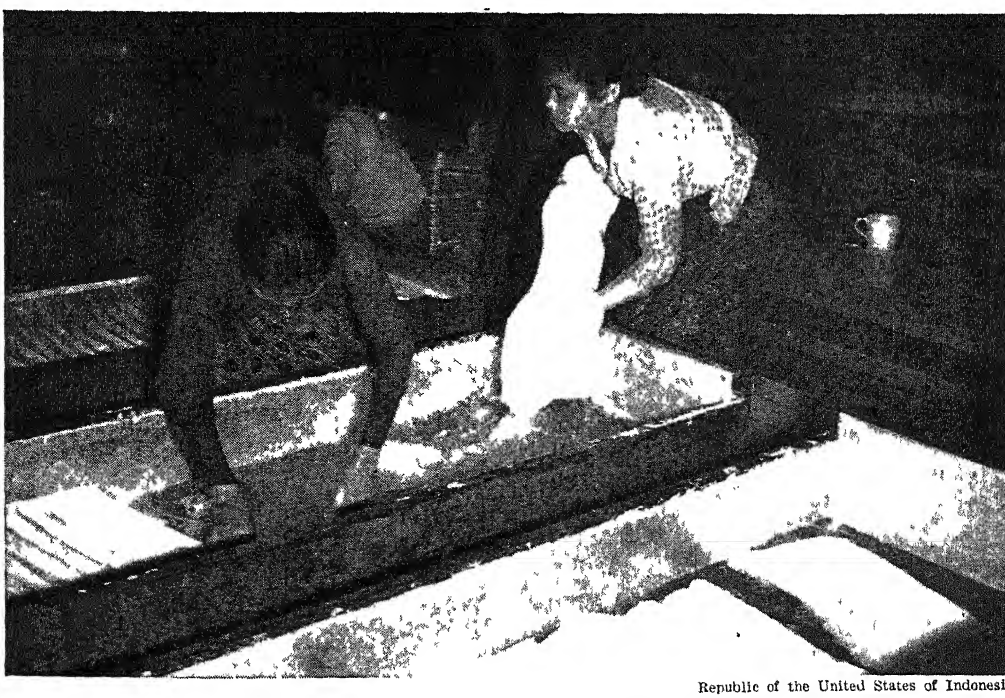
He started his rubber experiments in a little dwelling, mixing the gum by hand, spreading it upon a marble slab with a rolling pin. First he mixed magnesia in the gum. It dried up the surface. He hopefully made rubber shoes with the mixture and stored them away. When the warm weather came, they were just a mass of melted gum.

In many places, through five long years of constant trial and failure, he experimented, mixing one chemical after another into his sticky masses of cooking rubber. His health was frail, but his faith in rubber so strong that he struggled on through poverty, sickness, and discouragement. Often his re-

IN AN INDONESIAN RUBBER FACTORY



The latex that workers have tapped from the *Hevea* trees of an Indonesian plantation has been brought to the rubber factory in large jugs. It is being poured into the tanks where it will be processed.



Republic of the United States of Indonesia

The treated latex has coagulated in the tanks in the form of thick slabs. The photograph shows the slabs being taken out of the tanks; they will now go to rolling machines to be flattened into sheets.

sults would seem successful. He would make things of his gum elastic, sell a few with enthusiasm, only to find they would not last through weather changes.

Through Nathaniel Hayward in Roxbury, he received his first knowledge of the use of sulphur as a drier of gum elastic and bought from Hayward the claim of combining the two. Goodyear and Hayward started to make life preservers, and received a government contract for mail bags. The mail bags decomposed in the factory. The life preservers which had been shipped out were returned as worthless.

Goodyear took his still unsolved problem back to the kitchen, mixing and rolling rubber and sulphur. Early in 1839 some of the mixture was accidentally brought in contact with a hot stove and, contrary to everything that had happened before, heat charred this rubber like leather but it was still flexible. Goodyear nailed it to the outside of the kitchen door and left it overnight in the cold. The cold did not affect it. The rubber seemed to be "cured." He made test after test to find how much heat and how much time were needed for a lasting result. He mixed rubber and sulphur day after day, and put them in his wife's oven.

At last, after years of work, he knew he had the solution. He could keep rubber from changing with the weather and make it permanently useful to man.

The solution was rubber plus sulphur plus heat, at the right temperature, for the right length of time. In 1843 he applied for the patent for this process of curing rubber, now called vulcanization after Vulcan, the Roman god of fire. That vulcanization, discovered by Goodyear, is vital in all rubber manufacturing today.

Henry Wickham and plantation rubber

During the reign of Queen Victoria, another practical step was made in rubber progress by a man of vision—a step that brought about the great modern rubber plantations. The man of vision was Henry Wickham. The practical step was the taking of rubber seeds from Brazil to England for planting.

The world's supply of rubber, up to this time, grew wild in the dense jungles of Brazil. The supply seemed limitless but natives collected it by most primitive methods, at great danger.

Of about 400 kinds of rubber trees and vines in the world that can give rubber milk, Wickham selected the *Hevea brasiliensis* as the most practical, the tree that should produce the best grade of rubber. With a small group of Indians, he went into the interior of Brazil to select seeds from the best type of 17 *Hevea* trees. Seeds had to be carefully packed, for they were filled with heavy oil that could become rancid and prevent germination. He dried them, and packed them between layers of dried wild banana leaves.

In June, 1876, Wickham arrived in Liverpool. A special train took him and his seeds to London where it is said Sir Joseph Hooker, Director of Kew Botanic Gardens, had thrown out rare orchids to make room for the rubber seeds. Within a few weeks, the rubber seedlings had sprouted and nearly 2,000 were shipped to the Eastern Tropic Botanical Gardens in Ceylon and the Malay Peninsula. During the next few years, rubber trees were transplanted to Singapore, Borneo, Malaya, and Java, making possible later the large modern plantations with their regular orchard system of plantings.

By the time automobile manufacturers were making their great demands for rubber, plantations in the Far East were able to help supply rubber in quantity. Strangest of all is the fact that about the time the source of rubber was shifting from Brazil to the Far East, the source of coffee was shifting from the Far East to Brazil.

A modern rubber plantation

A rubber plantation looks like a well kept orchard, with thousands upon thousands of tall *Hevea* trees stretching out in long, regular rows. Between the trees is no treacherous jungle growth but only

a low, creeping bean plant which acts both as a green fertilizer and as ground cover to suppress jungle growth and check soil erosion.

Developing these plantations in the East Indies years ago meant uprooting the jungle, building roads, bridges, railroads, caring for thousands of workers —another adventurous chapter in the romance of rubber!

The rubber is a liquid milk-like fluid called latex, found in the thin layer of cells in the tree bark. It is *not* the life sap of the tree and is *not* obtained by boring a hole in the tree. Tapping is a most delicate operation which, properly done, does not in any way injure the tree, for the tree bark and fluid renew themselves as do the white corpuscles in our blood.

Workers start at daylight because the latex runs more freely in the cool of the early morning, after the coolness of the tropical night. Each tapper is responsible for about 300 trees. There is no delay. The latex immediately starts its steady drip-drip from the cells along the cut down into the cup, running from one to two drops a second. Drip varies with the seasons and the weather.

At the next tapping, another cut is made just below the first. Each is so small that with thirty successive tappings not more than two inches of bark are removed. This section is called the tapping panel. Actually, trees are "rested" half the year, being tapped alternate days, weeks or months. This means that 12 inches are tapped a year on one-half of the tree or 36 inches are tapped over three years. For that reason, the low end of the first tapping cut is set up at 36 inches from the ground. Nature starts at once replacing the bark where the cut is made so that after six years, when the tapper comes back to where he first started, cuts are covered with new bark that can be tapped again.

Rubber milk as it drips from the trees is about 60 per cent water, 28 per cent chemically pure rubber, the balance resins, minerals, proteins, and sugars. The rubber is suspended in the form of a large number of minute globules.

Getting it ready to ship is a complex procedure that requires precise knowledge of this highly perishable liquid. It comes to the United States in one of two dry forms (smoked sheet or crepe rubber) or in liquid form (latex).

If it is to travel in dry form, the rubber milk is put in large tanks and diluted with water so it will coagulate more easily. Acetic or formic acid is added and within six to sixteen hours, the rubber coagulates and comes drifting to the top in thick water-soaked slabs.

SEEDS OF THE RUBBER TREE

The finest quality rubber is produced by a tree called *Hevea brasiliensis* because it came from Brazil. Shown here are *Hevea* seeds.

Next it goes through a series of rollers to squeeze out the water and is dried, either by the smoking and heat-drying process which takes 48 hours and gives us amber brown smoked sheet rubber, or by the air-drying process which takes two weeks and gives us light yellow crepe rubber. If it is to travel in liquid form, it is speedily poured into tanks and a preservative added such as ammonia.

A full grown *Hevea* tree averages 30 to 60 feet in height and its average life

is 40 years or more. But how are new trees grown? Again it is all scientifically worked out. High up in the tree are the seed-bearing pods, around 300 to a tree. They are about the size of a goose egg, smooth and green, with two or three seeds in a pod. The pods contain formations of gas which explode when the seeds are ripe and may throw them as far as 100 feet. Between July and October—depending upon weather conditions—they burst, with sounds not unlike pistol shots.

When a new rubber area is to be planted, seeds from only the healthiest, highest-yielding mother trees are collected. These are planted in nursery beds. Soon after they have sprouted, they are transplanted in regular rows in the new area—about 150 seedlings to an acre. Climatic and soil conditions are so good that the seedlings grow rapidly. In about a year, they are ready for the most wonderful of all modern plantation improvements—bud-grafting.

BUD-GRAFTING A RUBBER TREE

In bud-grafting, an "eye" is cut out of the green branch of a selected mother tree and grafted on the stump of a year-old seedling. The graft is bandaged for a month, during which time the little "eye" takes hold and develops. When it sprouts, the top of the seedling is cut off.

Bud-grafting is very important because it is considered the only way to get a true replica of the original tree. It is a simple but highly skillful operation, responsible for much of the increased yield in rubber from the *Hevea* tree.

Because of careful selection of seeds, "eyes," plants, and thorough research on the nutritious conditions of the soil, the potential production of one acre of *Hevea* trees has been increased from 400 pounds an acre a year to several times that amount.

After planting the rubber seed, five years must pass before the *Hevea* tree can be tapped for latex. Not for another seven years—or twelve years from the time of planting—does the tree come to full productivity. Each year during the first seven years of tapping, the tree increases its yield. In full yield, a tree may give from one to over four gallons of rubber milk in the course of a year.

Chemistry makes rubber serviceable

Rubber as it comes from the plantation would be of no use to us. It is the chemists who make rubber serve us in so many ways. The magic of rubber today is the magic of chemistry, for it is chemistry that produces rubber with hundreds of different uses. The rubber industry is really a chemical industry.

The prime property of rubber is that when it is distorted by pulling or pushing, it will go back to its original size and shape. It is the only known natural material with this property. Rubber can be made to stretch from 50 to 1000 per cent or made so it has no stretch at all (hard rubber). Modern chemistry, plus Charles Goodyear's discovery, vulcanization, not only controls the degree of stretch but also gives rubber its wide variety of other properties. How? By deciding what substances to mix with it when it is in its

original pliable state, the quantity of each substance and the time and temperature of vulcanization so that the rubber will have the properties necessary for the work it has to do.

Scientists in large research laboratories work the year round on new uses for rubber, new ways to make present products last longer, wear better, and cost less. Our present rubber goods serve us better because of many recent chemical developments in the laboratories. The two most important are two kinds of organic chemicals, (1) accelerators which not only hasten vulcanization but make much better products and widely increase the scope of products, and (2) antioxidants or age resisters which reduce the action of the oxygen in air on rubber and lengthen the useful life of all rubber products.

Latex made commercially available

In 1920 the general laboratories of the United States Rubber Company cooperating with its Far Eastern plantations began experiments which later led to significant changes in the rubber industry. Up until this time, all rubber used in the manufacture of products was in a solid or dry form, as crepe or smoked sheets. By chemical treatment natural rubber latex in liquid form was made available to manufacturers. It was later compounded for special purposes and used still in liquid form. This enabled the rubber manufacturers to improve the quality of some products and to develop new rubber products which had never been made before.

Characteristic uses of rubber in liquid form include the impregnation of artificial leathers, carpet back sizing, cushions, insulated wire and cables, mattresses and mattress materials, nonwoven rugs and fabrics, paper sizes, and self-sealing bandages; also, dipping of balloons, bath caps, bathing suits, drug sundries, gloves, hot water bottles, toys, and novelties; also, molding and extruding of advertising novelties, abrasive wheels, battery plates, foam sponge, and elastic thread.

Reclaimed rubber

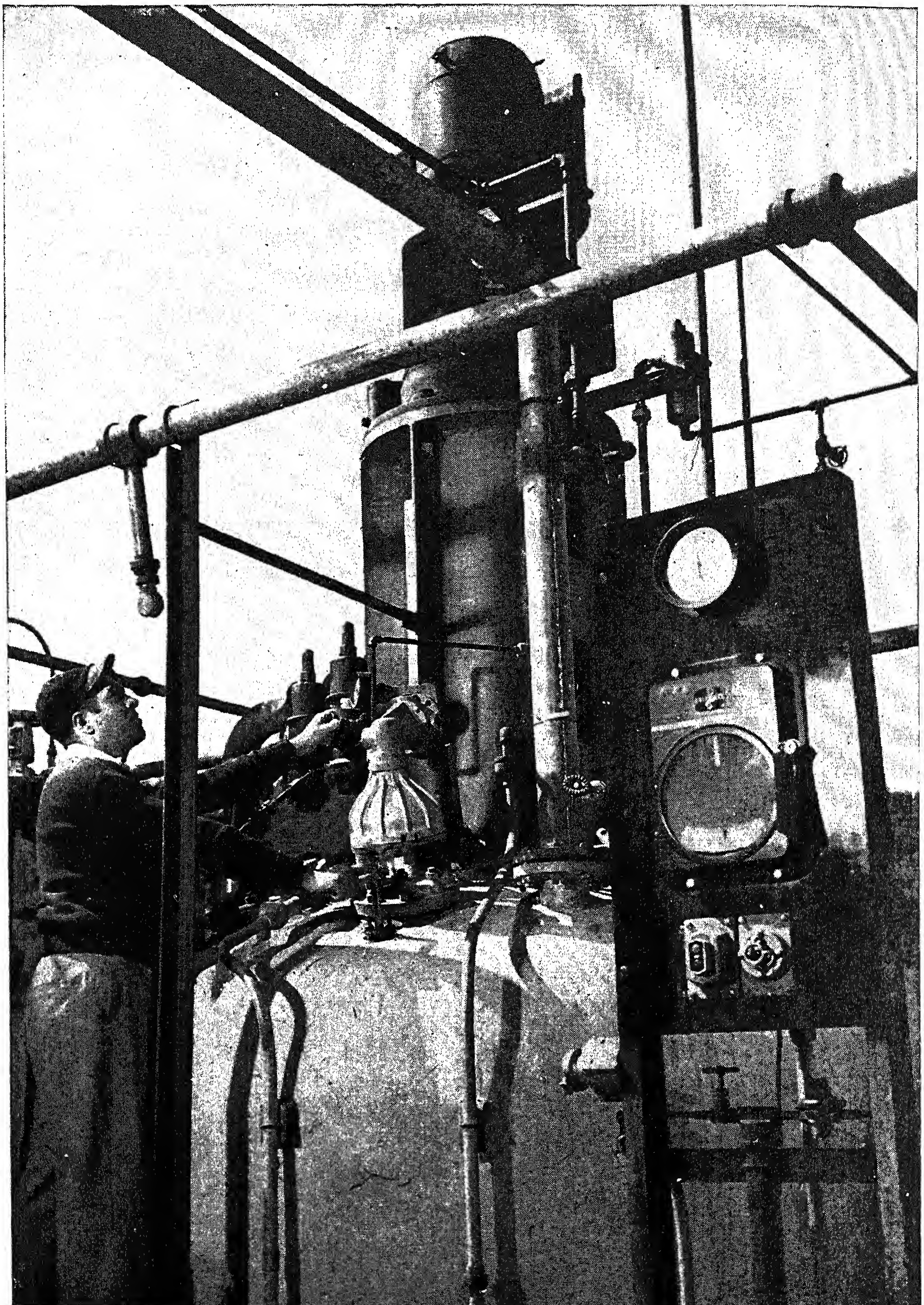
Reclaimed rubber is economically important in the rubber industry, and in some applications is superior to crude. However, reclaim is used in almost all cases in combination with crude. A few products made wholly of reclaimed rubber are frequently cheaper substitutes for better products made of crude or combinations of crude with proper amounts of reclaim.

Firestone News Bureau

Collecting latex in a rubber plantation of Liberia, West Africa. The tree was tapped early in the morning; the white latex then flowed for a period of three or four hours into a cup. A worker is pouring the latex from the cup into a collecting bucket. A worker can tap 300 trees a day.

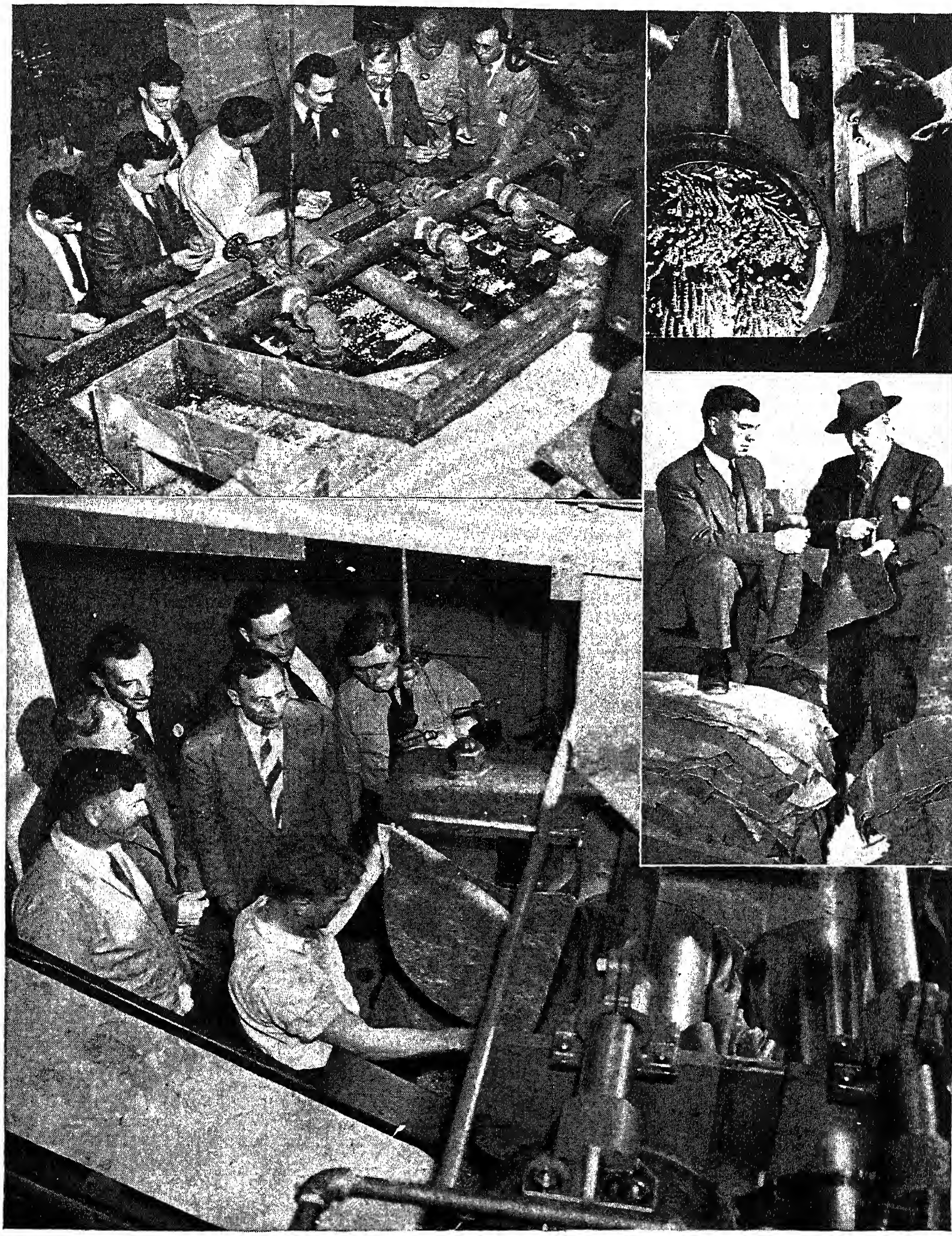
In reclaiming used rubber, the reclaimer is told the properties a reclaim should have and the use for which it is intended, and builds a reclaim for that particular purpose. The reclaimer will select from his stock piles the used rubber articles which will give him the de-

MANUFACTURING SYNTHETIC RUBBER



The actual manufacture of buna-S synthetic rubber is called polymerization, which means hooking up molecules into long chains. It is accomplished in rows of vessels called reactors. Here an operator is checking the gauges of one of several lines of reactors at a synthetic rubber plant.

SYNTHETIC RUBBER IN THE MAKING



Upper left, this operation shows particles of the buna-S synthetic rubber being separated from water; water containing the rubber particles is flowing down through a trough onto a vibrating screen, seen under the pipes. The white material on the screen is synthetic rubber. Upper right, after washing, the synthetic rubber is forced over a screen and through holes to break up the larger pieces and to remove excess water before going to the tunnel drier. Lower left, rubber coming out of the mill. Center right, after drying and milling operations, slabs of the synthetic rubber are cut to commercial size. The men are examining and testing a sheet.

sired composition in his finished reclaim. The reclaiming process consists of grinding up the scrap, removing foreign particles, dissolving and washing out fabrics and chemicals. The stock is then softened or plasticized and refined by milling on rolls.

Synthetic rubber

Natural rubber is a polymer of isoprene. Isoprene is a hydrocarbon, and a polymer means that the original molecules have been linked together like box cars in a long train to form a giant molecule of several thousand units.

The so-called synthetic rubbers are polymers of other related hydrocarbons. They differ chemically but have many of the properties of natural rubber. Although the Germans made and used a synthetic rubber in 1915, it was a poor product and they discontinued its manufacture after World War I. The first commercially successful synthetic rubber made in any country was neoprene, the polymer of chloroprene, introduced by E. I. du Pont de Nemours & Company in 1931. In 1932, Thiokol was produced in the United States, and in 1935 the buna rubbers—polymers and co-polymers of butadiene—were first produced in Germany.

Although there are many variations and trade names, there are actually just five types of synthetic rubber: (1) buna-S, (2) buna-N, (3) neoprene, (4) butyl, and (5) Thiokol.

The buna-S type is a co-polymer of butadiene, C_4H_6, and styrene, $C_2H_3\ (C_6H_5)$; this type was chosen in 1942 for the major part of the synthetic program in the United States. The S refers to styrene. Large, additional buna-S plants were built and operated for the Government by United States Rubber Company, Firestone Tire and Rubber Company, The B. F. Goodrich Company, The Goodyear Tire and Rubber Company, Copolymer Corporation, and General Tire and Rubber Company.

The buna-N type consists of co-polymers of butadiene and acrylonitrile, or vinylcyanide, C_2H_3CN. The N refers to the nitrile or cyanide radical. The buna-N type synthetic rubbers include the following: Perbunan, made by Standard Oil Company (New Jersey) and The Firestone Tire and Rubber Company; Hycar, by Hycar Chemical Company, owned by Phillips Petroleum Company and The B. F. Goodrich Company; Chemigum, by The Goodyear Tire and Rubber Company; Thiokol RD, by Thiokol Corporation, associated with The Dow Chemical Company.

The neoprenes, polymers of chloroprene, C_4H_5Cl, were developed by du Pont.

Butyl rubber is a co-polymer of isobutylene, C_4H_8, and small amounts of other unsaturated hydrocarbons such as butadiene, C_4H_6 or isoprene, C_5H_8. Butyl rubber is a development of Standard Oil Company (New Jersey).

The commercial synthetic rubbers differ from natural rubber in their individual characteristics. Each synthetic has many types, and in some cases, several manufacturers. In general, however, the following conclusions may be pointed out: (1) Synthetic rubbers are different from natural rubber in processing characteristics and in some cases are more difficult to process (2) Natural rubber is superior to synthetic in most performance characteristics. (3) Synthetics are superior to natural rubber in resistance to most influences that cause deterioration.

The United States Government's synthetic rubber program in World War II was a complete success. Rayon in synthetic rubber truck tires improved performance 375 per cent as compared with tires made with cotton. By 1945, all-synthetic passenger car tires were at least 90 per cent as good as pre-war natural rubber tires. In the larger sizes, because of the heat built up in synthetic rubber tires, not all have been efficient without the use of some natural rubber. This applies particularly to those driven at high speeds and with heavy loads, and especially in warm climates.

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OUR LIQUID GOLD

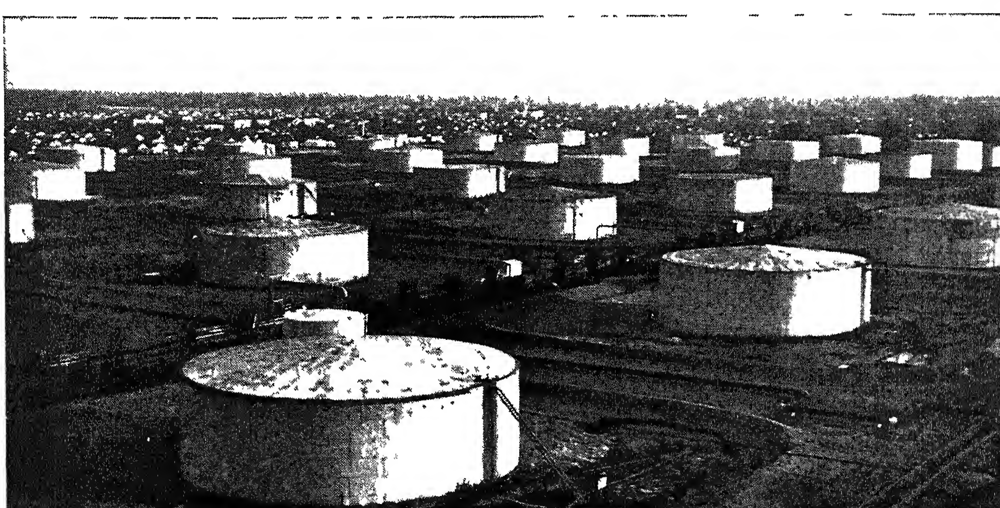
Energy Sources Pent Up for Ages in the Depths of the Earth

PETROLEUM (rock oil) has been called "liquid gold," not because of its color or beauty, but because of its value in our modern civilization. It is, of course, of much greater usefulness than gold. Our agriculture, industry, transportation and communication depend upon petroleum in hundreds of ways, and the possession or lack of it can vitally affect the fortunes of a nation, both in peace and war. For this reason, petroleum plays an important and sometimes sinister part in the forming of the foreign policies of various governments.

The enormous world-wide demand for petroleum has grown up within the present century, especially since petroleum products began to be used as fuel for power in gasoline, Diesel and other types of engines. Before that time its chief uses had been for heating, lighting and lubrication.

Nevertheless, although the first commercial oil well was sunk as recently as 1859 near Titusville, Pennsylvania, man has been making use of petroleum for various purposes as far back as we have any human records. The dark, sticky crude oil has always seeped and oozed from cracks in the earth in many parts of the world. We read about petroleum in the Bible, where in most translations it is called "pitch." The Book of Genesis tells how, when Noah built the Ark, God instructed him to "pitch it within and without with pitch" to make the vessel watertight. Further on in the Bible we read of the mother of Moses using pitch to calk the little cradle-boat in which she hid her baby from the Egyptians.

Archaeologists have found that petroleum was used by the Persians nearly six thousand years ago as mortar in buildings and as a kind of glue for other purposes. Herodotus, the Greek traveler, in the fifth cen-



Standard Oil Co. (N. J.), photo by Libsohn

Tank farm, Baton Rouge refinery. A tank farm consists of a number of storage tanks clustered together. The capacity of the tanks ranges from a few hundred barrels to many thousands of barrels.

Standard Oil Co (N J)

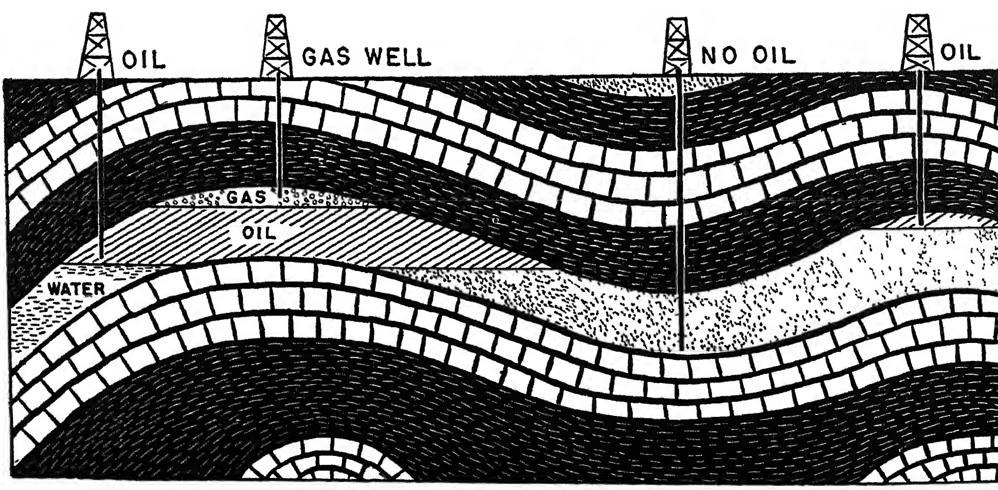
Colonel Edwin L. Drake (right), standing near the first oil well at Titusville, Pennsylvania

tury B.C., had quite a bit to say about the use of petroleum in the Persian Empire. He described the process of drawing the oil out of the shallow surface wells, commenting that it was "dark and evil-smelling."

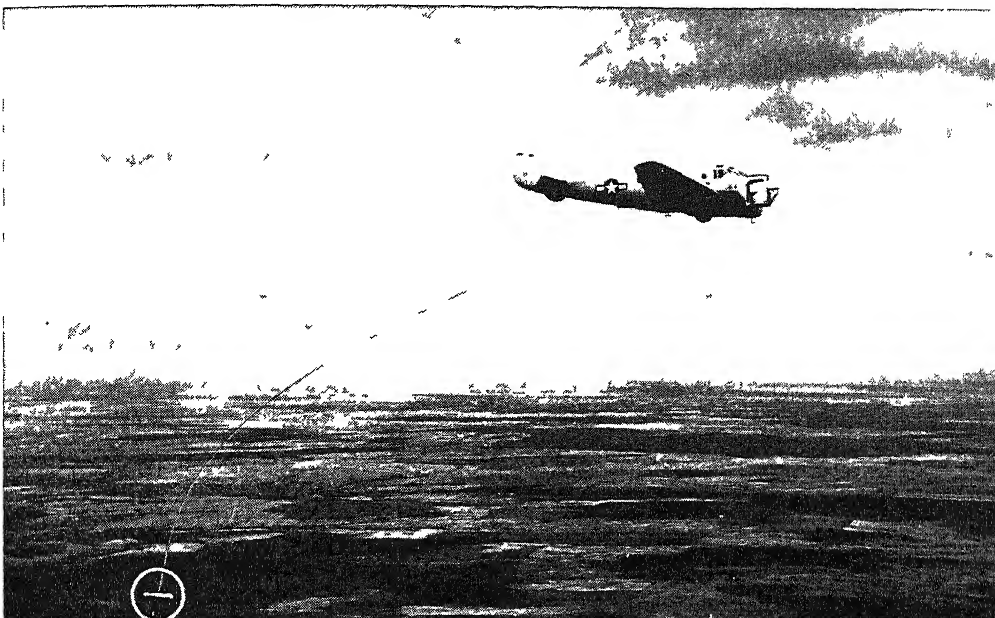
Throughout that part of the world which we now call the Middle East there were a great many seepages. These sometimes caught on fire and became the "eternal fires" of the Persian fire-worshipers. It was the ancient Persians who seem to have invented petroleum warfare, shooting arrows tipped with burning pitch into the ranks of their enemies.

Another famous tourist, Marco Polo, the Venetian, visited the oil fields of Baku toward the end of the thirteenth century on his way to the court of Kublai Khan. He told of "a fountain from which oil springs in great abundance, inasmuch as a hundred shiploads might be taken from it at one time," and added that "this oil is not good to use with food, but it is good to burn" He also mentioned that the people used the gaseous oil for lighting and cooking, and as an ointment to cure camels of the mange Baku, which is on the Caspian Sea, is now a part of Russia and is one of the world's famous producing fields.

The early explorers of North America found oil oozing out of the ground or floating on the surface of water in many places. In his diary, the explorer of the Northwest Alexander Mackenzie wrote on August 2, 1789: "When we came to the river of Bear Lake . . we experienced a very sulphurous smell, and at length discovered that the whole bank was on fire for a very considerable distance. It proved to be a coal mine to which the fire had communicated from an old Indian encampment. The beach was covered with coals and the English Chief gathered some of the softest he could find, as a black dye; it being the mineral, as he



The various layers of limestone (blocks), sandstone (stipple) and shale (black, with white lines) in a typical oil field. Oil and gas are imprisoned in a kind of pocket with a dome-shaped roof.



U. S. Geological Survey

Prospecting for oil with a magnetic detector (indicated by a white circle). It measures the variations in the earth's magnetic field resulting from the presence of different kinds of rocks

informed me, with which the natives render their quills black."

What Mackenzie took for coal was really the thick oil from one of the many seepages of petroleum in the general neighborhood of what is now the Fort Norman oil field, which proved of such value during World War II.

The Indians used to rub their bodies with this mineral oil, believing that it toned up their muscles and made them active and quick. After the eastern part of the country became settled, the white people also began to use it to a certain extent. Sometimes they would recover the oil by soaking blankets in the seepages and then squeezing the oil out of them into vessels. Sometimes they could get it by skimming floating patches from the surface of the water. Very little was obtained by these means, and it was sold at a high price for medical purposes. Peddlers sold it under such names as Seneca oil or Indian oil, and it was supposed to be a wonderful cure-all. It was rubbed on externally to cure rheumatism and also taken internally as a medicine. It is said that most people used about a pint a year, which does not seem to have been

Standard Oil Co. (N. J.), photo by Lofman

Like the magnetic detector in the top picture, this magnetometer identifies the layers of rock.

Standard Oil Co (N. J.), photo by Collier

A geologist, employed by an oil company, examining a sample of rock recovered from an outcrop.

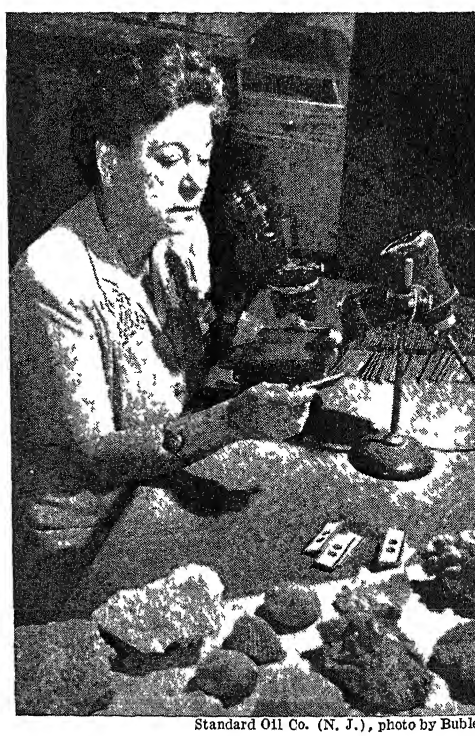
excessive medication.

In western Virginia, about the year 1806, men boring wells to get salt water kept finding oil mixed in with the brine. They were greatly provoked because the oil interfered with the usefulness of the salt wells; naturally at that time no one could have envisioned the golden future of petroleum in commerce and industry.

It was not until 1846 that oil for burning was obtained from coal by a Dr. Abraham Gesner of Nova Scotia. Dr. Gesner called this oil "kerosene," from the Greek word for "wax." A company was formed to manufacture it, and it was so successful that other coal-oil companies were established. This brought about a new interest in petroleum. Professor Benjamin Silliman of Yale College conducted some experiments on Oil Creek in Pennsylvania and found that this oil from the earth was quite as good for burning as oil from coal. Indeed, in 1848 some had been sold for this purpose by a man named Samuel M. Kier. He charged $1.50 a gallon for it.

It was from such small beginnings that the vast petroleum industry of today grew. Because of the growing demand for petroleum, people who owned oil-ruined salt wells began to market this oil in order to get some return from their property. There were many such wells around Titusville, Pennsylvania, and it was there that a group of businessmen decided to drill for oil, making use of the derricks and other equipment employed in drilling salt wells. The group engaged a retired railroad conductor, Edwin L. Drake, to take charge of the enterprise. Drake got hold of an expert driller of salt wells, William A. Smith, and this man, with his two sons, brought in the first drilled well in the spring of 1859.

Fortunately Drake had hit upon an excellent site for the first attempt, but it did not seem so fortunate in the beginning. Rock was struck at a depth of thirty-six feet, and after that the makeshift equipment could bore at the rate of only three feet a day. People in the neighborhood began to call the well "Drake's Folly." The work was continued, however, and finally, nearly four months after the well was started, oil was struck. The Smiths had stopped operations to measure the depth of the hole, which had reached about sixty-nine feet.



Standard Oil Co. (N. J.), photo by Bubley

Examining rock specimens under the microscope.

They found that the thick black oil had risen to within a few inches of the top of the hole. With a crude pitcher pump they managed to pump several barrels of the oil before night fell.

Petroleum is found to some extent in every continent, in many islands of the sea, and even beneath the oceans. As we have seen, it sometimes occurs quite near the surface of the earth, but most of it is stored between the layers of rock farther down—indeed, no one yet knows the greatest depth at which it exists, although wells have been drilled to a depth of 15,000 feet.

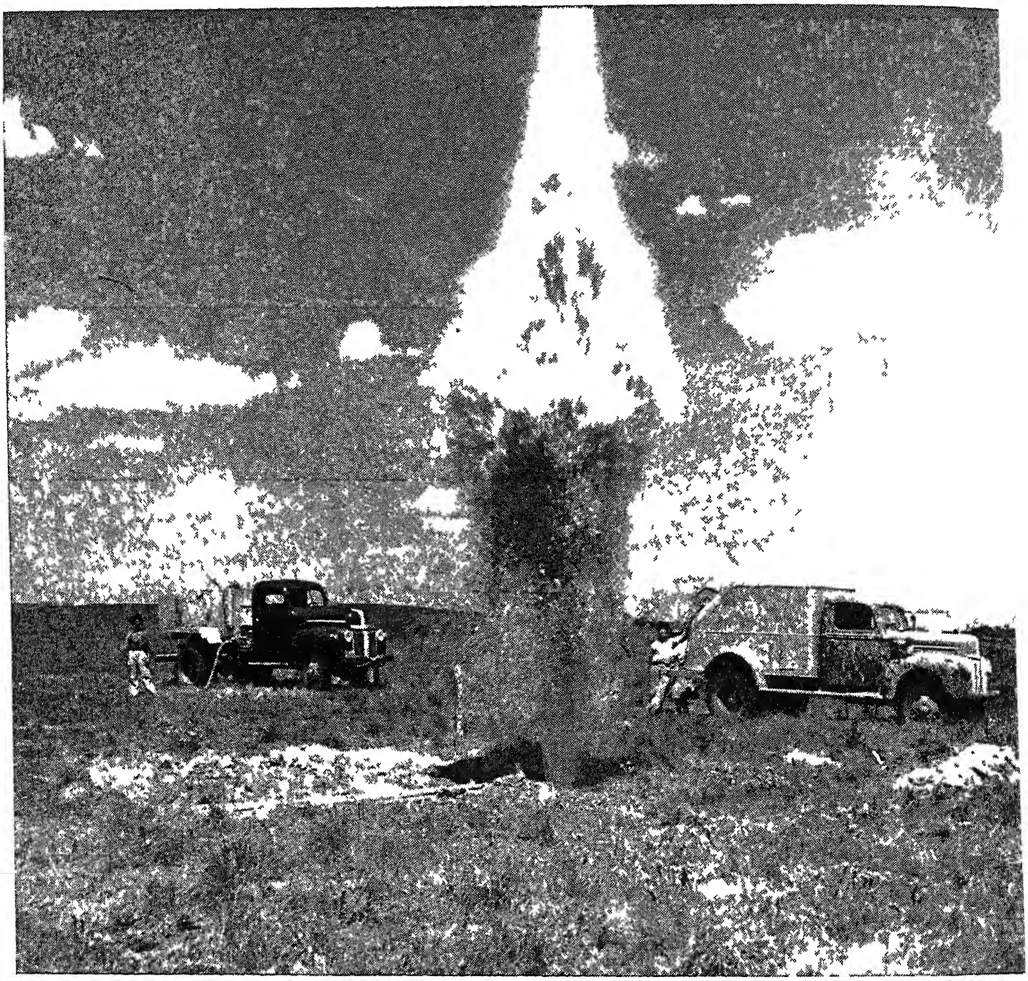
Like coal, petroleum is the product of the great changes that took place in the crust of the earth during long geological periods. It is found between the layers of sedimentary rocks from the Cambrian to the Recent, a length of time now estimated to have been about 550,000,000 years, and it was originally made up of marine animal and vegetable life left by the seas that covered different parts of the earth at intervals during these long ages of geological time.

The pools that successful drillings reach are usually in anticlines—dome-like spaces where the layers of rock have been pushed up in folds. The oil is contained in the porous, spongelike layers of rock, such as limestone or sandstone, and when these layers (properly called strata) are roofed over with harder rock we have an ideal oil field. Gas and brine (salt water) are trapped with the oil, and it is the pressure of the escaping gas that forces the oil to the surface of the earth when the drill reaches its goal. Until oil engineers devised means of controlling this pressure a great deal of valuable oil and gas was wasted when a newly drilled well brought in a "gusher."

Oil is also found in oil shale, a compact sedimentary rock from which the petroleum has to be taken by what is called destructive distillation. Scotland and the state of New South Wales in Australia produce oil in this way, though on a relatively small scale. Another form of oil deposit that cannot be drilled for is typified by the Athabasca tar sands in Alberta, Canada. This area of hun-

Standard Oil Co. (N. J.), photo by Collier

Gravity meter in operation. Its delicate springs register the gravity pull of the subsurface rocks.



Standard Oil Co (N J), photo by Collier

The seismograph at work. A charge of dynamite has just been set off far below the surface of the ground, delicate instruments within the "seismo" truck register the vibrations caused by the blast.

dreds of square miles contains the largest known accumulation of oil on earth. So far the oil geologists have only been able to guess at the amount of oil contained in these sands, but the official guesses have gone as high as 200,000,000,000 barrels (a barrel is forty-two gallons). The importance of this potential source of oil can be easily appreciated when we remember that recent estimates of the world's *discovered* oil reserves were only 77,647,000,000 barrels.

Whether the oil in the Athabasca sands will ever be of any use depends entirely on man's devising ways to extract it from the sands at a cost within reason. It was announced early in 1951 that the province of Alberta, which owns the area, the National Research Council of Canada and experts from the petroleum industry believed that they had found the solution of this problem, and that processes had been developed that would enable this field to be brought into production on a commercial scale.

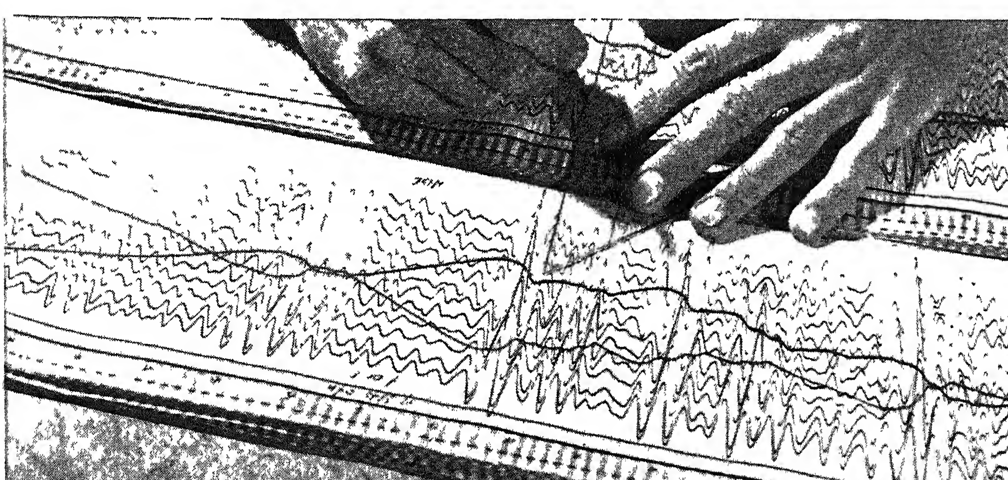
Drilling an oil well is an expensive process under any circumstances. The cost depends to a great extent upon the depth to which the well has to be drilled and the hardness and thickness of the rock through which the drill has to go. On the average, the cost of drilling may range from a hundred thousand to half a million dollars.

This high cost makes it necessary for the drillers to be reasonably sure that there is oil under the exact spot where they erect their rigging. To help obtain this knowledge both the geologist and the physicist have contributed.

During a generation or more the regions of the earth have been studied intensively to determine which areas are likely to be petroliferous—petroleum-bearing Surveys of various kinds are made, including the use of aerial photography. In order actually to locate oil in regions where it is believed to exist, such devices as gravity meters, magnetometers and seismographs may be used. The power of the earth's pull is greater for a heavy rock near the surface than it is for one farther down or for a light rock. By using the gravity meter, the variations in gravity can be measured and the deformations of underground rock layers can be studied; in this way traps containing oil may be detected. The different kinds of rocks under the surface of the earth affect the earth's magnetic fields, and the variations thus caused can be measured by the magnetometer. The seismograph, as we know, is used primarily for measuring and locating earthquakes, but it is also helpful in locating oil domes or pockets under the earth. The geophysicist simply creates a miniature earthquake by setting off a heavy charge of dynamite Then, by means of his portable seismograph he can determine the speed at which the echo from each kind of rock comes back to him. From these echoes he can chart the rocks underground and discover where the rocks are humped into a dome or other structures worth drilling.

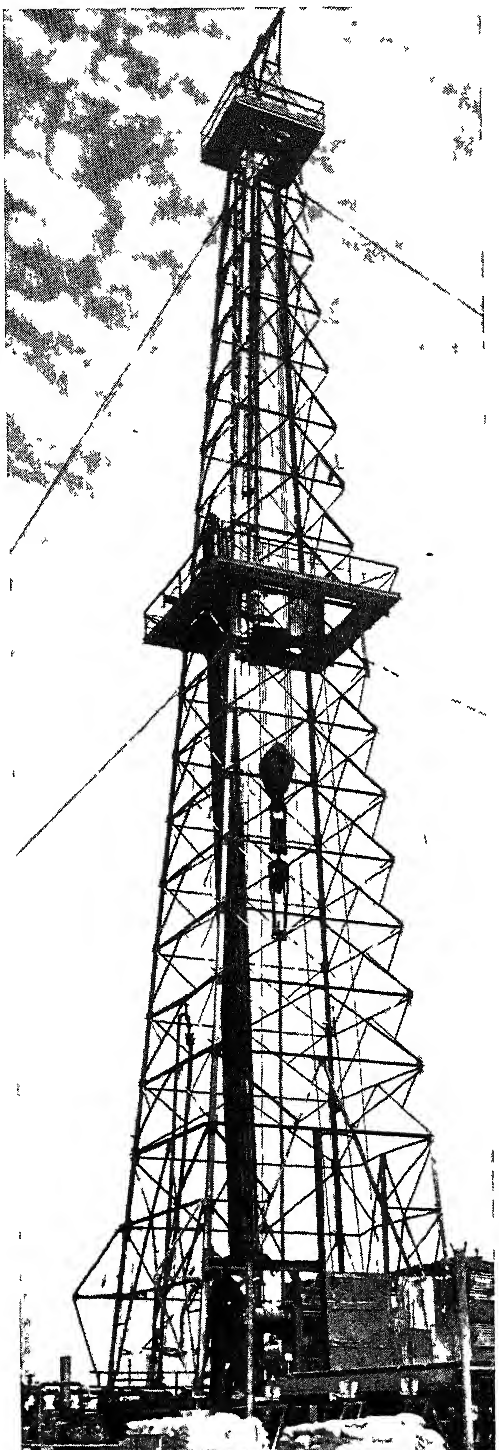
To check even more closely on the nature of the rocks, and on the presence of oil, gas and water, further tests are made while the well is being drilled. This is done by means of an electric device, which is lowered into the well. It sends an electric current through the surrounding strata, recording differences in resistance to the current. In spite of these and other scientific tools, not every drilling operation is successful.

The oldest drilling method in use is called cable-tool drilling. This was used to drill the famous oil well at Titusville in 1859, but that well was only sixty-nine feet deep. In cable-tool drilling, the hole for the well is punched into the ground by a heavy, sharp cutting tool (bit) attached to the end of a cable. The bit is raised and dropped over and over again until the necessary depth has been reached. Really deep wells could not be drilled by this method, but it was widely used until about 1920. Since then a method called rotary drilling has largely taken its place.



Standard Oil Co. (N. J.), photo by Bubley

Vibrations caused by a dynamite blast are recorded on the above seismogram. Different kinds of rocks transmit the echoes of a blast at different speeds: hence this seismogram shows rock structure.



Standard Oil Co. (N. J.), photo by Collier

The towering oil-well derrick that is shown above is used for raising and lowering drill equipment.

In sinking a modern oil well the first step is to dig a large pit to hold machinery and pipe connections. Then, directly over the drilling site, a steel framework tower is built. This is the derrick, and it may be as tall as a seventeen-story building. It is used for raising and lowering drilling equipment into the well.

An account of the modern method of drilling for oil

In rotary drilling a hole is bored into the earth by a bit attached to a hollow drill pipe, which is connected with a large flat wheel, or turntable, resting on the floor of the derrick. The turntable is power-driven and the bits themselves are large and heavy. The drill works in much the same way that a carpenter's drill bores holes in wood, but the bits are of extremely hard steel, hollow through the center, and designed in a variety of types. One widely used type of bit has ridged rollers at the bottom, and as it rotates the rollers can grind the rock into powder, thus speeding up the process of boring.

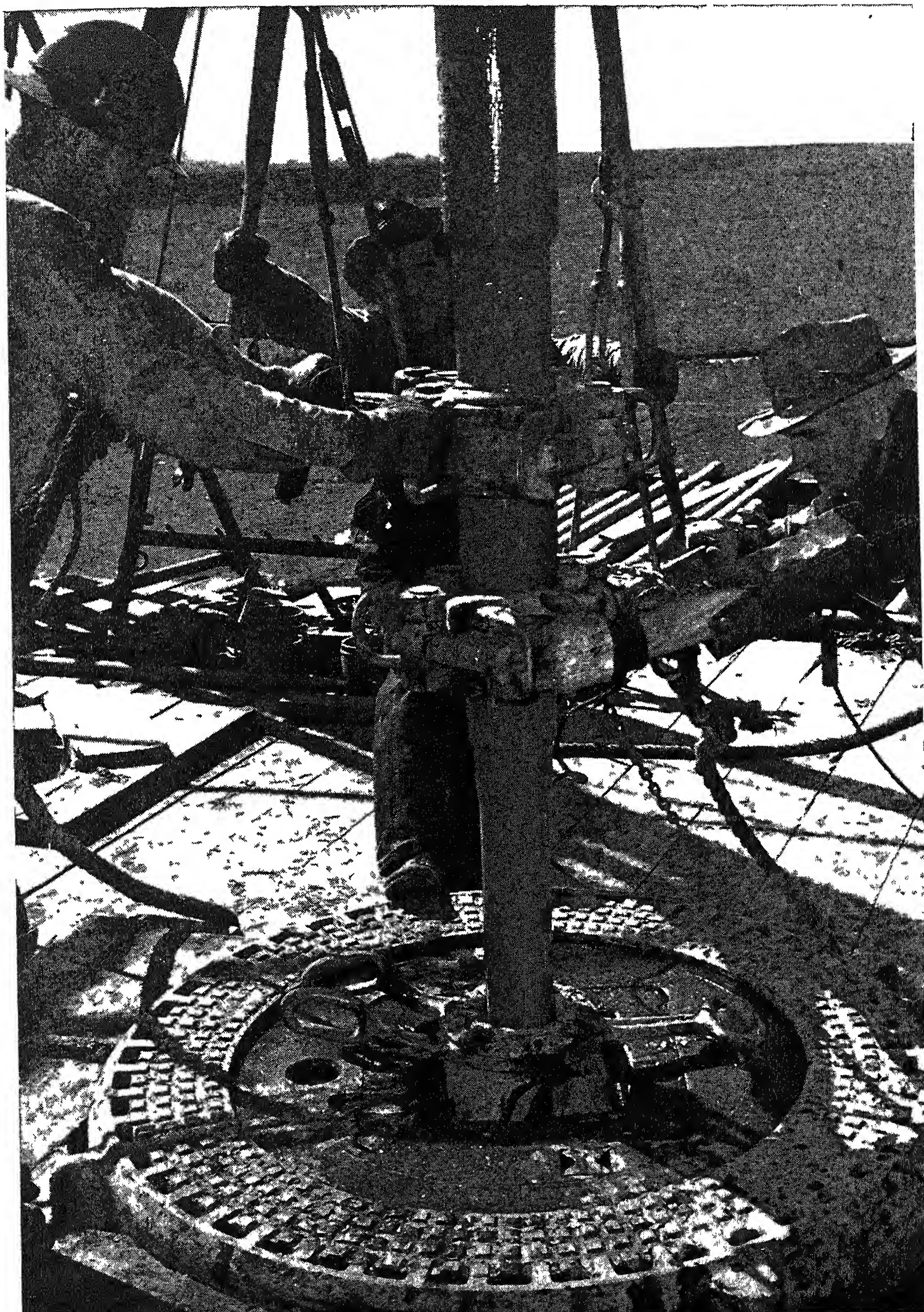
As the drill pipe cuts through the rock formations it penetrates deeper and deeper into the ground; new sections of pipe are then fitted to the top. When oil has been reached the drill pipe and bit are removed

To keep the steel drill bit from overheating, a stream of mud is constantly forced down under pressure through the drill pipe and the hollow center of the bit This mud is of a very special kind, made by mixing certain clays and chemicals with water.

Utilizing mud to plaster the walls of the bore hole

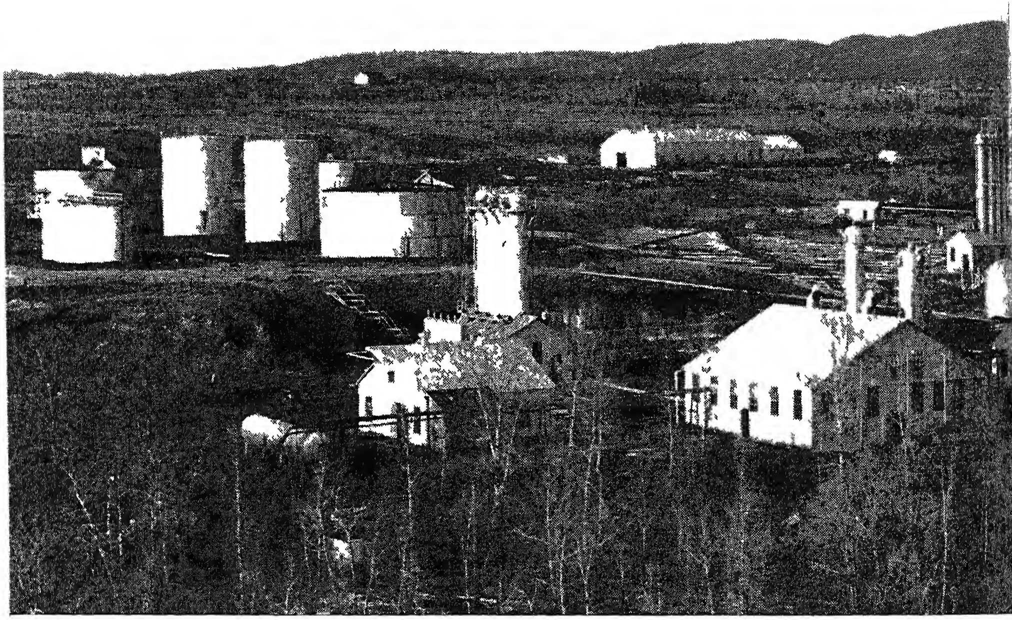
After the mud passes through the hollow center of the bit, it returns outside the bit and pipe to the surface, carrying fine rock shavings with it. This serves to plaster the walls of the deepening hole, helping to prevent cave-ins. When the gas, oil and water are finally reached, the mud holds back the pressure so that the flow can be more readily controlled.

As the bore hole goes deeper into the earth its sides are lined with steel pipe,



Standard Oil Co (N J), photo by Lofman

Power-driven rotating table, used in drilling for oil. A hollow drill pipe passes through the center of the table and rotates with it. New sections are added to the pipe as it penetrates deeper.

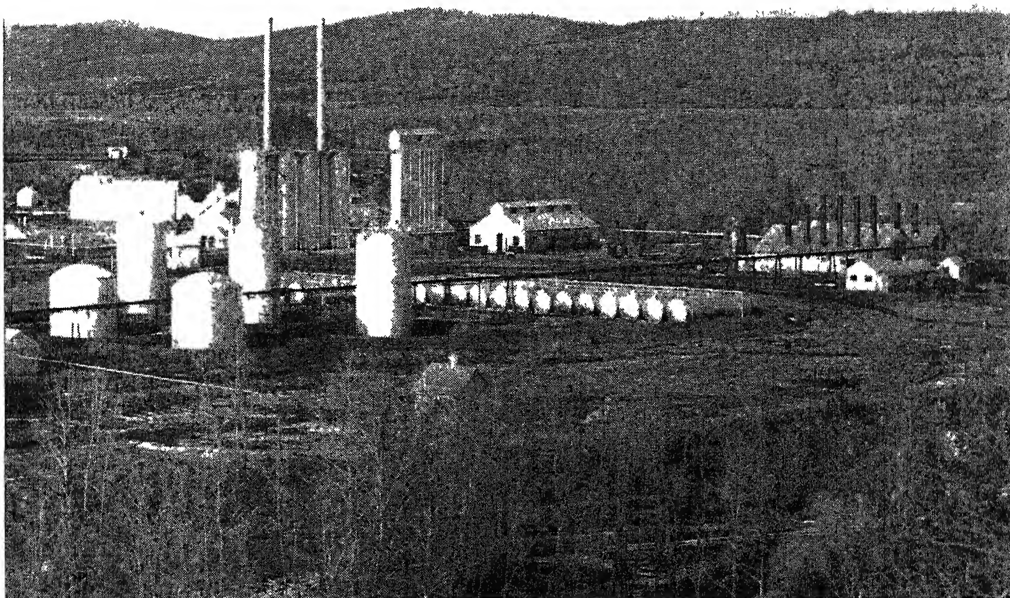


General view of the Royalite oil plant in Turner Valley, in the foothills to the southwest of Cal-

called casing, each length of pipe fitting into the one above it as the well extends farther downward. Then, when the required depth has been reached, a special kind of tubing, from two to two and a half inches in diameter, is lowered through the casing until it runs the entire length of the well. The space between the tubing and the casing is sealed, so that the oil has to go through the tubing to get to the surface. Valves and meters attached to the top of the tubing control and measure the flow of the oil. Ordinarily the natural pressure is enough to make a newly drilled well flow, but if, as sometimes happens, there is not enough pressure, pumps are used to bring the oil up. Pumping is also done when the pressure at the bottom of a well becomes exhausted.

As the oil and gas rise toward the surface, the pressure grows less and this causes the two substances, which have been in solution, to separate. At the top of the well the mixture passes into a separator, which completes the process, so that the gas-free oil may be piped into gathering tanks. If there is not very much gas it is often burned at the well. If, however, there is a great deal of gas in an oil field, it is gathered and piped from the different wells to a central plant, where it is processed and broken down into different types of gas. Some of these gases may be sent back to the oil wells to keep up the pressure, others may be used to make carbon black and other products, or may be fed to main transmission pipes and eventually used for cooking, heating and other fuel purposes.

If you have ever seen an oil field, or even pictures of one, you will have noticed the number of large storage tanks clustered together in what is called a tank farm. These may run in size from a few hundred to several thousand barrels capacity, ac-



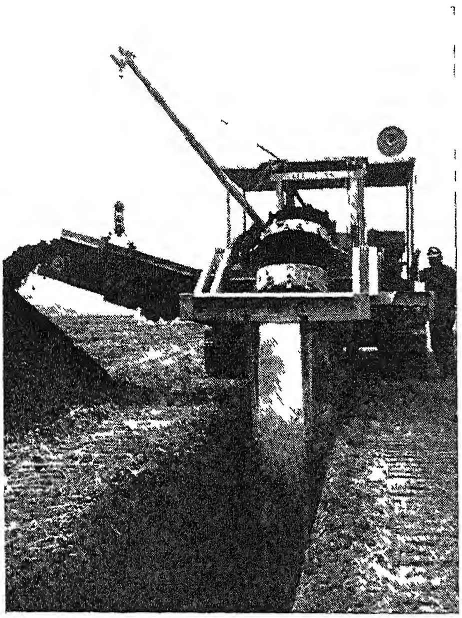
H Pollard

gary, Alberta The big province of Alberta accounts for most of Canada's production of petroleum

cording to the production of the wells. In the really big tank farms it is quite common to see tanks of 55,000- and 80,000-barrels capacity. Other groups of storage tanks may be seen at key points along pipe lines, at ports where oil is loaded on tankers and at the refineries to which the crude oil goes to be processed for the market. An enormous amount of crude petroleum is constantly kept stored in such tanks in all parts of the world In the United States alone the usual amount in storage since the end of World War II has been nearly 250,000,000 barrels, while world storage as a whole has been roughly 350,000,000 barrels. These huge supplies are needed for seasonal demands, and to keep up the working stock of the refineries.

Transportation is the life of the petroleum industry. In the early years of the industry, when the refineries were near the oil fields, oil in its various forms was readily transported in barrels by wagons, barges and railways. In recent years, however, great oil fields have been developed in regions far away from the centers of population and industry, and the crude oil is carried to refineries near the big markets by pipe line or tanker, depending upon whether it is being moved overland or by water. Railroad tank cars and even trucks are sometimes used to carry crude oil from fields that are not reached by pipe lines, but most of the tank cars and trucks that you see are carrying the refined fuel oils and gasoline to the distributing centers.

The oil tanker is of great importance in transporting crude petroleum, not only because that is the only way to take the stuff across seas and oceans, but also because of the low cost of shipping by inland waterways. Lake tankers carry oil from Canadian pipe-line terminals through the Great Lakes, and great strings of barges float down the



Richard Finnie

Digging a trench for a pipe line. The machine moves on caterpillar tracks as its wheel revolves

Ohio and Mississippi rivers to the western and southern refineries and to the Gulf of Mexico ports.

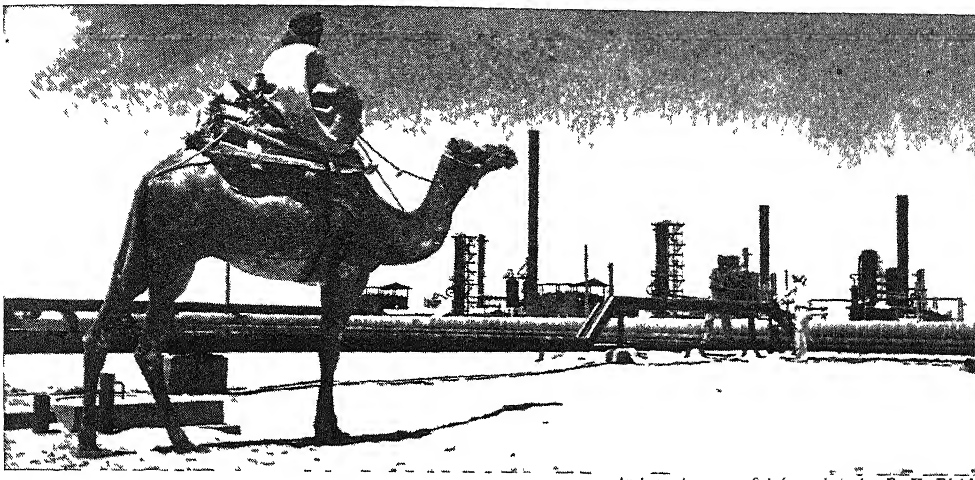
The first seagoing ship to carry a cargo of oil was probably the 224-ton brig Elizabeth Watts, which sailed for England from Philadelphia in 1861. This sailing vessel carried her cargo in barrels. It was not until eight years later that an oil ship equipped with iron tanks appeared. This was the Charles, a sailing vessel of 774 tons, with 59 tanks. The first vessel to be specially built as an oil tanker is said to have been built in England in 1886. Its hull was divided into compartments for different types of oil.

The average tanker today has a displacement of about 16,000 tons, but there are many larger ones of more than 28,000-tons displacement, carrying as much as 240,000 barrels of oil. The modern tankers are built with many safety and fire-prevention devices, comfortable quarters for the officers and crew and such navigation equipment as radar, sonic depth finders and gyroscopic compasses.

We have seen that pipe of one sort or another is used to convey oil from the time it leaves the underground reservoir on its journey to the surface of the earth. Pipes carry it from wellhead to gathering tank and from gathering tank to storage tank These, however, useful and necessary as they no doubt are, do not stir the imagination as do the great arterial pipe lines that carry hundreds of thousands of barrels of oil under fields and woodlands, across swamps, through burning sand dunes or frozen tundra to terminals hundreds of miles away.

The United States alone has more than 110,000 miles of pipe line. This does not include the "Big Inch" and "Little Inch" built during World War II to carry oil from the Texas fields to New York. These are now used to transport natural gas. Next to the United States in pipe-line mileage comes Soviet Russia, which is believed to have pipe lines totaling 3,500 miles The Canol pipe line, built during World War II to carry oil from Norman Wells in the Canadian Northwest Territories to Whitehorse in the Yukon, is not now in use. A much-needed pipe line was brought into use in December 1950 when oil from the new Alberta oil fields reached Superior, Wisconsin, at the Head of the Lakes, from there to be shipped in tankers to the refineries at Sarnia, Ontario. This Edmonton-Great

Road gang preparing to place a pipe line in the



Arabian American Oil Co., photo by R. Y. Richie
Where past and present meet: a burnoose-clad guard, mounted on a camel, patrols a stretch of an Arabian pipe line. The Middle East is rich in oil fields, some of which have not yet been exploited.

Lakes pipe line is 1,200 miles long and goes through the provinces of Alberta and Saskatchewan and the state of Wisconsin on its long underground journey.

A number of pipe lines have been and are being built in the great oil fields of the Middle East, though their progress in certain of the Arab states has been slowed up by disturbed political conditions. The Iraq pipe lines were the first to cross the Syrian desert, from the Kirkuk fields to the shores of the Mediterranean. One of these lines, which has its terminal in Tripoli, was completed in 1949. The one to Haifa was delayed by events arising from the Palestine troubles.

The Trans-Arabian pipe line was undertaken to avoid shipping the oil from the fields along the Persian Gulf, through the Arabian Sea and up through the Red Sea and the Suez Canal to the Mediterranean—a slow and expensive 3,600 miles as against

Standard Oil Co. (N. J.)
trench that has just been dug for it. In an average day about 10,000 feet of pipe can be laid.

1,000 for the pipe line.

Petroleum is a very complex substance —it is really many things in one, and that is why we are able to obtain from it so many different but related substances: gases, liquids and solids. It really consists of a large number of hydrocarbons (compounds containing only hydrogen and carbon) all mixed together. The variations in these hydrocarbons are responsible for the differing characteristics of the substances produced by the refineries.

A modern oil refinery is a jungle of steel towers and spheres

A modern refinery is an amazingly complicated affair, even just to look at. The larger plants cover many acres and seem at first sight to be veritable jungles of tall steel towers, enormous metal spheres and vast furnaces, entwined with miles and miles of pipe. Oil refining is really a big chemical-engineering industry, and its basic processes are distillation and cracking.

The simplest example of separating a liquid from a solid that is dissolved in it is the distilling of salt water. In this, the steam from the boiling water is made to go through a pipe or coil into a vessel in which it cools and condenses into water again. The salt stays behind. If the salt-water solution also contained another liquid with a lower boiling point than water, it could be evaporated and condensed first. In that way all three substances could be separated.

The distillation of petroleum liquids is very complicated

The distillation of petroleum liquids follows the same principle, but it is much more complicated. Some of these liquids boil at temperatures below 70° Fahrenheit, but others need more than 600°. The boiling points of many of the petroleum liquids are so close to one another that they must be separated in groups, or "fractions." Others can be completely separated in the first distilling operation.

The distillation apparatus that is used at the present time is called the tubular continuous process type. In this tubular or pipe still, the crude oil is pumped through a pipe that winds around and around a heated chamber until the oil reaches a temperature of about 800° F. Then it passes into the lower part of a tall steel tower called a "fractionator" because in it the oil is separated into different fractions, such as gasoline, kerosene and heating oil. This operation is called a single flash.

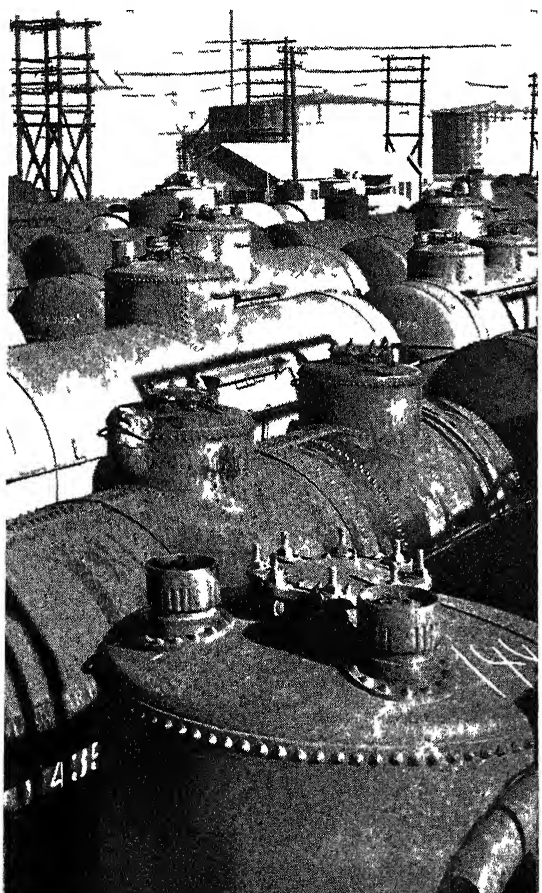
A fractionating tower may be as much as a hundred feet high, and it has perforated steel trays spaced from ten to twenty-four inches apart all the way up to the top. As the hot oil vapor makes its way to the top of the fractionator it has to pass through these trays. The vapor gets cooler as it goes up, so that the hydrocarbons that have the highest boiling point are condensed on the bottom trays, those that have the next highest boiling point condense on the next

These tank cars, at a large oil refinery, are go-

trays, and so on to the top. Only the lowest boiling fractions—gas and gasoline—stay in vapor form long enough to reach the top. As the different fractions condense on the trays they are drawn off and passed through a smaller tower called a stripper to purify them still further.

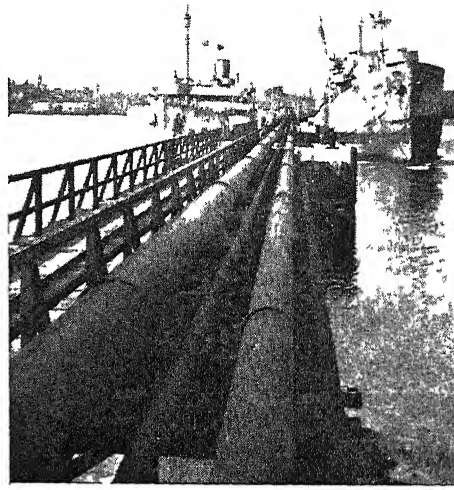
The other important process, called cracking, was developed to increase the amount of gasoline that could be got from the crude oil. This is done by actually breaking the molecules in the heavier part of the crude oil into the lighter molecules required for gasoline. More than twice as much gasoline can be obtained from the oil in this way. After the cracking process the oil is redistilled in order to separate out the gasoline that has been formed.

Several different methods of cracking



Standard Oil Co. (N. J.), photo by Corsini

ing to be filled with various petroleum products.



Standard Oil Co (N. J.) photo by Parks

These two tankers are emptying their cargo of crude oil at the Portland, Oregon, pipe-line docks

have been developed, one of which, called fluid catalytic cracking, was used during World War II for making 100-octane aviation gasoline and the hydrocarbon gases that are used in the manufacture of synthetic rubber.

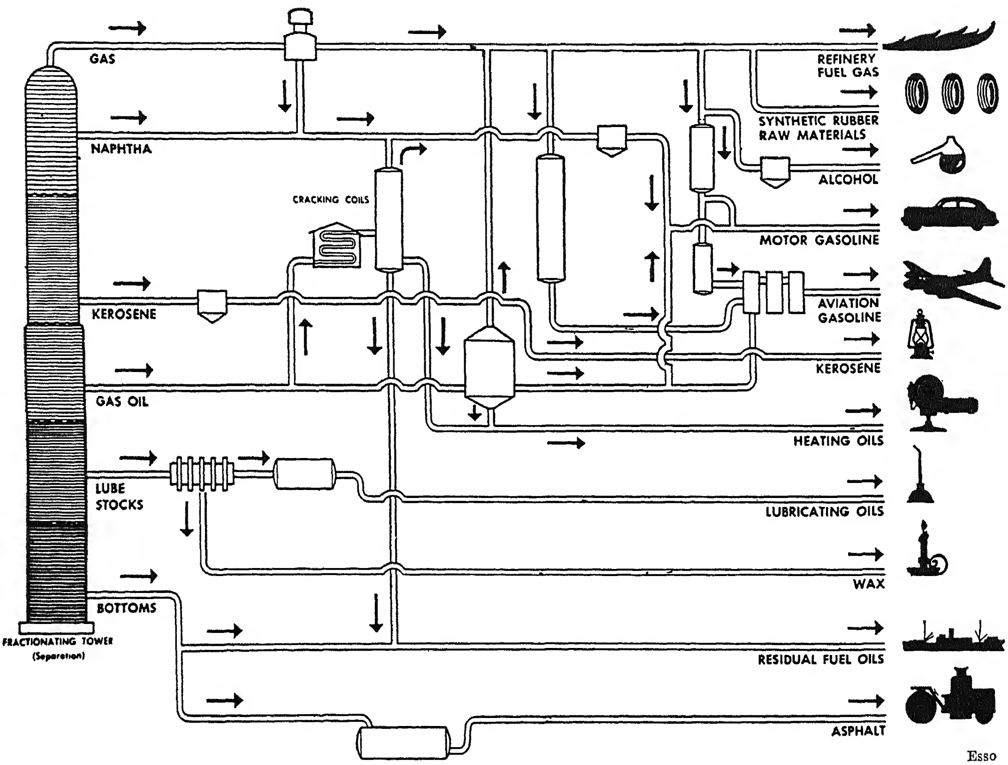
Research has found a number of methods of taking the hydrocarbon molecules apart and rearranging them to fit particular purposes such as forming special kinds of gasoline. One process is called isomerization It is used to rearrange the carbon and hydrogen atoms in the molecules into a pattern that will make a gasoline engine work more smoothly. Another process, called hydrogenation, also reduces sulfur and nitrogen impurities in gasoline. This process consists of adding hydrogen atoms to molecules that are deficient in these atoms. Alkylation is a method used to join together molecules of natural and cracked refinery gases, and polymerization is a process by means of which two smaller gaseous molecules can be united into one larger one—quite the reverse of cracking.

The products of crude petroleum have thousands of uses, many more than it would be possible to describe in this article. From

the hydrocarbon gases and the naphthas we get substances used in making paints and lacquers, perfumes, explosives, the saccharin that some people have to use instead of sugar for sweetening, and all the colors of the rainbow for dyeing cloth. The waxes and greases produce such varied things as printing ink oils, lipstick and wrinkle removers, floor wax and lubricating greases. Asphalt is used to pave our streets, to roof our buildings, and to make rubber substitutes. Other useful products of petroleum include antifreeze mixtures, weed-killers, insecticides, plastics, soaps and anesthetics.

Important as these and other products have become in our everyday lives, they represent only a small fraction of the amount of petroleum that is used for liquid fuels. Some authorities estimate that all the organic chemicals, including rubber and alcohol, needed to supply the whole world for a year could be made from ten days' production of crude oil. However, the oil-chemical field is growing in importance all the time, and new synthetic materials are constantly being developed. As the world's living standards are raised, these uses of petroleum will increase and spread, for there are a great many materials that can be produced cheaply and on a large scale only from petroleum.

It has been estimated that out of 100 gallons of crude oil, 37 gallons of gasoline are produced and 39 gallons of fuel oil. Kerosene and lubricants account for about 7 gallons, and the remaining 17 gallons represent miscellaneous products. This emphasizes the fact that by far the greatest use of petroleum is for fuel for light, heat and power.

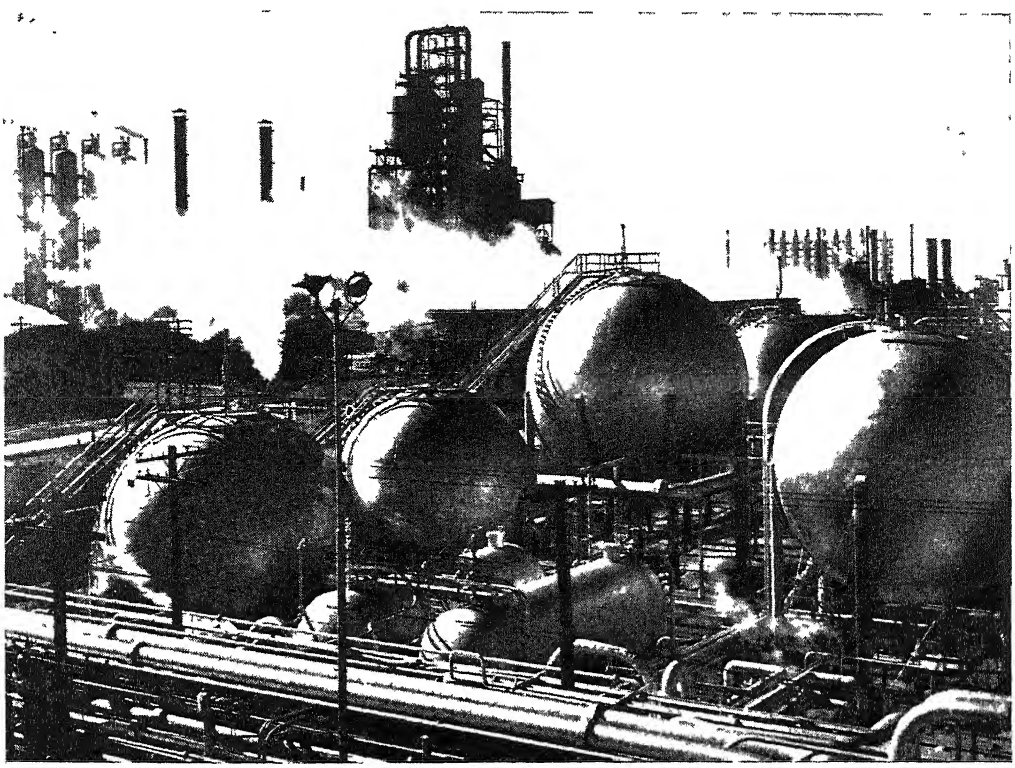


In the fractionating tower, which is shown at the left, the crude oil is heated. Molecules, in order of their lightness, float upward as gases, are drawn off and cooled into liquids again. In this way crude oil is converted into such products as gasoline, kerosene, lubricating oils and asphalt.

The word "fuel" means anything that will combine with oxygen to make fire, but for

practical purposes there are relatively few substances that can be converted into commercial fuel. Fuel can be solid, liquid or gaseous. The first fuel ever used was probably wood, though, as we have seen, the ancient Persians and Syrians did make some use of crude petroleum.

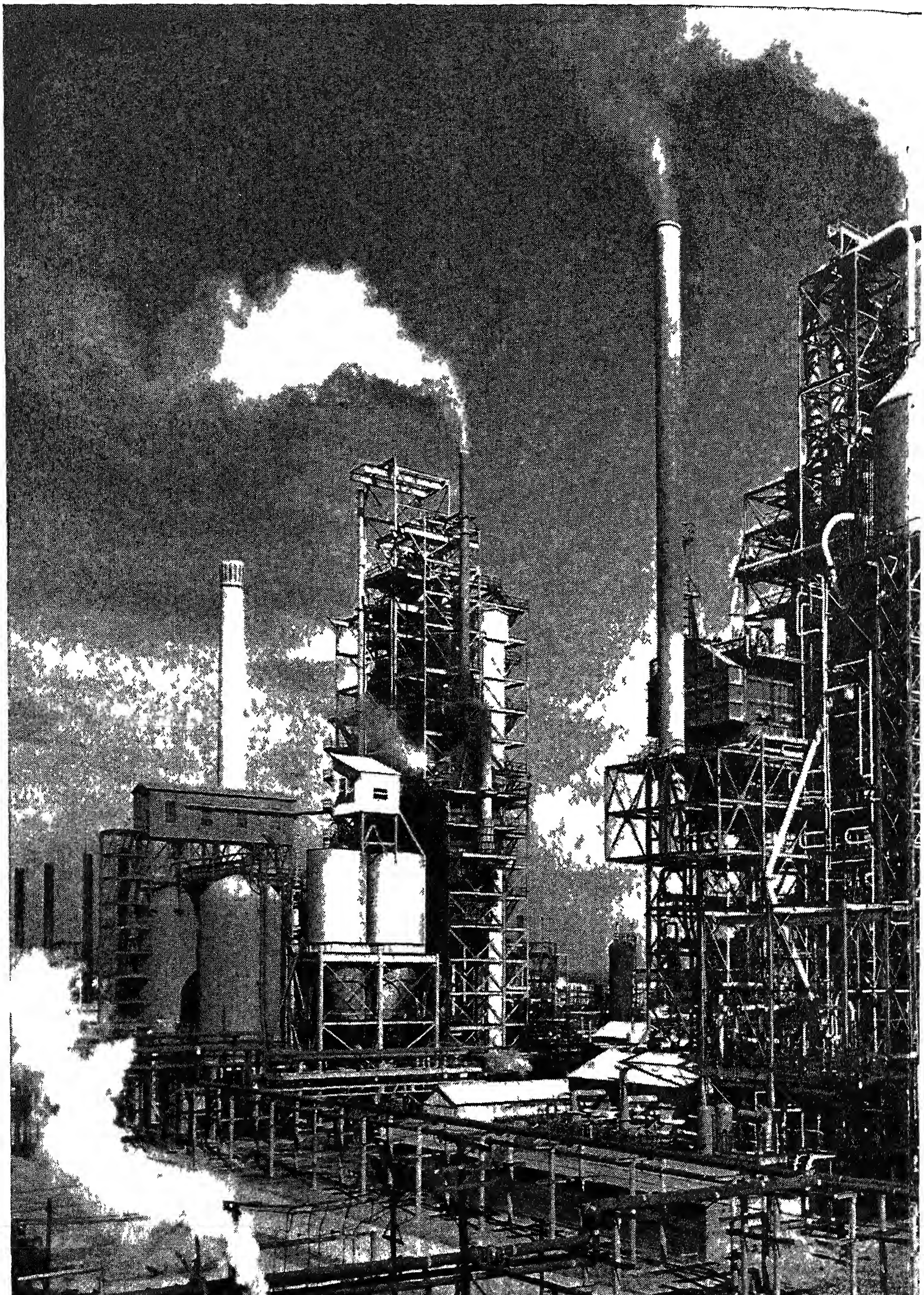
To serve as fuel, a substance must be easy to obtain, store and use, and a unit weight of the fuel must, when burned, give off sufficient heat rapidly enough to serve a domestic or industrial purpose. In order to compare the heating values of fuels, a convenient system of measurement is used called British thermal units (B.T.U.). This term signifies the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit—as from 60° to 61° F. Liquid fuels, especially petroleum, generate many more B.T.U. per pound than do solid fuels. A unit pound of liquid petroleum gives about 19,000 B.T.U., compared with 13,000 B.T.U. from a pound of average coal. Charcoal gives only 11,000 and seasoned wood gives between 5,400 and 6,800 B.T.U. per pound. It is easier to maintain an even heat by mechanically regulating the burning of oil than by using coal or wood. With oil, it is possible to develop an intense heat quickly and to shut it off just as suddenly. Gases will do this too, but greater care must be taken to prevent leakage and explosions.



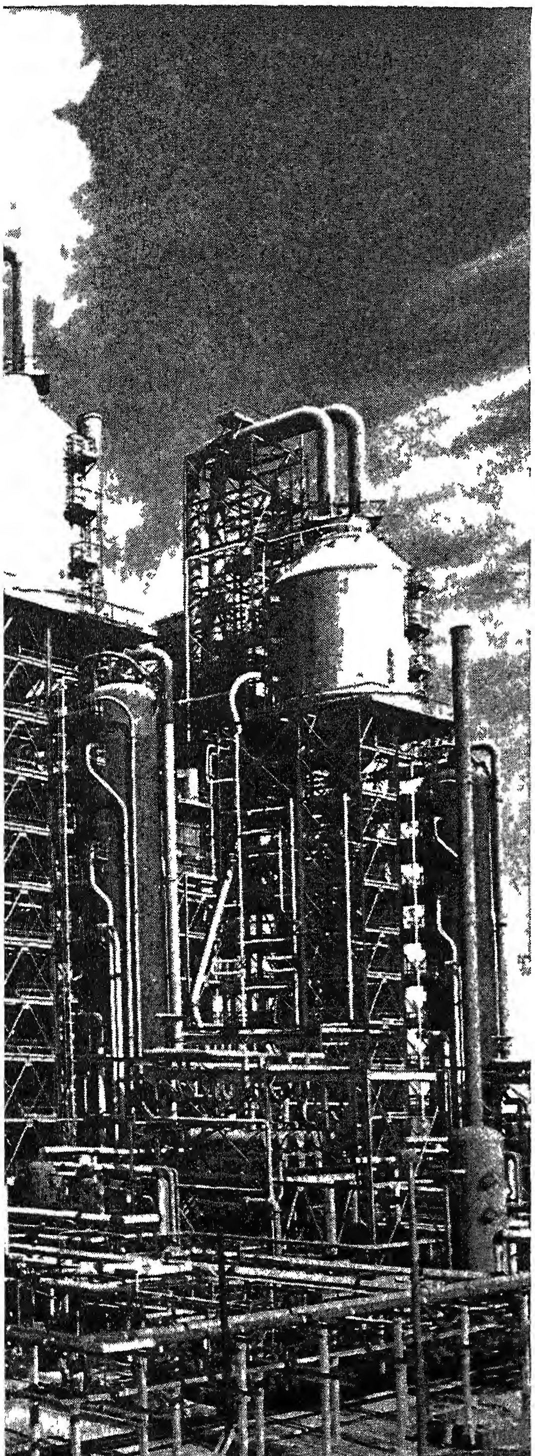
Standard Oil Co. (N. J.), photo by Corsini

Storage tanks for butadiene, a product of the cracking of petroleum and an important ingredient in the manufacture of several different kinds of synthetic rubber. German chemists, some years before the beginning of World War II, were the first to grasp the industrial possibilities of butadiene.

Today the liquid fuel most used for power is gasoline, especially for planes and automobiles, but an enormous amount of the heavier oil known as Diesel oil is also used. Diesel engines are employed on railroad locomotives and in ships of every size from great ocean liners to small pleasure cruisers. Busses and heavy trucks are often run by Diesels, and so are many of the generators



Three catalytic crackers Cracking utilizes very high temperatures and pressures to decompose the



Standard Oil Co (N J), photo by Rosskam

heavier parts of petroleum into lighter products

that produce the electricity that lights our streets and houses Labor-saving machinery in industrial plants, mines, lumber camps and quarries, on construction jobs and farms is frequently powered by Diesel engines It is not surprising, therefore, that in the United States alone at least 71,000,000 barrels of fuel oil are burned in a year

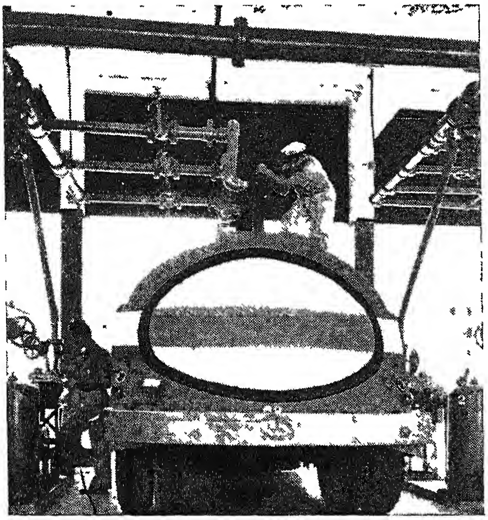
Some countries export most of the oil that they produce

Petroleum is not used on such a tremendous scale in all continents and countries, in fact, some of the countries that, at the present time, produce a great deal of oil export nearly all of it Others have to import most of the oil they consume According to a survey made just before World War II, North America was the only continent where production and consumption balanced each other South America used only about a fourth of the oil it produced, and Asia about half Europe, on the other hand, used nearly twice as much as it produced, and Africa, eighteen times as much Oceania (Australia, New Zealand, Fiji Islands and Hawaiian Islands) imported practically all the oil that it used

The United States is the world's biggest oil producer

For almost ninety years the United States was self-sufficient in petroleum, producing enough for its own needs and exporting to other countries as well In 1948, however, the United States became a net petroleum importer, that is to say, it imported more than it exported Today Canada and the United States consume at least two-thirds of the world's oil production Yet the United States is still the biggest oil producer and Canada is likely to become an important exporter of oil within the next few years

We have mentioned that the places where oil is to be looked for are those regions where marine sediments have existed through the geologic ages since the Cambrian. This does not mean, however, that wells can be brought in just anywhere and everywhere in such regions In some areas the sediments have been so altered and disturbed throughout the ages that there is



Standard Oil Co. (N. J.), photo by N. Morris

On its way to the ultimate consumer: loading a gasoline distribution truck at a depot in Havana.

little petroleum in them. In other places the oil may be so far under the earth as to be inaccessible. Nevertheless, there is a great deal more petroleum available under the rocks than has yet been prospected and discovered. As more exploration is done, more oil fields are being discovered and proved.

The petroleum resources of the world are not readily renewable like other natural resources that we possess—the crops that provide us with food, the water that we drink, the air that we take into our lungs. It is true that the natural petroleum-making process that we described in the first part of this article is still going on. But this process is so slow compared with the rate at which we are using up petroleum that we must regard our liquid gold as an asset that cannot be replaced once it has been all used up.

However, there are still large petroleum reserves in the earth. Oil-prospecting will undoubtedly turn up new reserves in the years to come. We shall be able, too, to add greatly to our stores by distillation from rock shale. Furthermore, we can obtain great quantities of petroleum products from natural gas and coal. It is likely, therefore, that our petroleum needs will be met for centuries to come.

An Estimate in Millions of Barrels of the World's Proved Reserves of Petroleum

The Caribbean area		Europe, except the U.S.S.R.	
Venezuela	9,000.0	Albania	9.0
Trinidad	250.0	Austria	75.0
Colombia	300.0	Czechoslovakia	2.0
Mexico	850.0	France	4.0
U.S.A., Caribbean part	9,986.0	Germany	45.0
Cuba	3.0	Great Britain	4.0
South America, except Caribbean area		Hungary	40.0
Ecuador	30.0	Italy	1.0
Peru	160.0	Netherlands	50.0
Bolivia	15.0	Poland	20.0
Argentina	250.0	Rumania	350.0
Chile	10.0	Yugoslavia	4.0
Brazil	15.0	Other Oil-Producing Countries	
North America, except Caribbean area		Algeria	1.0
Canada	500.0	British Borneo	150.0
U.S.A., except Caribbean	17,339.9	Burma	50.0
The Middle East		China, Formosa	20.0
Iran	7,000.0		
Iraq	5,000.0		
Kuwait	10,950.0	India, Pakistan	32.0
Qatar	500.0		
Saudi Arabia	9,000.0	Indonesia	1,000.0
Bahrein	170.0	New Guinea (Australian)	50 0
Egypt	120.0	Morocco	1.0
Turkey	1.0	Japan	15.0
The U.S.S.R.	4,275.0	Total, World	77,647.0

ATOMIC ENERGY

Boundless Power from the Core of the Atom

IN AUGUST 1945, the second World War was ended by the explosion of two atomic bombs over Japan. In each bomb about one pound of atomic explosive reacted or "blew up." The energy released by the reaction of this single pound of material was the same as that set free by the explosion of some 20,000 tons of old-fashioned TNT.

Man's accomplishment in releasing and controlling the awful energies locked deep within the heart of the atom is one of the most important milestones in his progress. If he handles this new power wisely, peaceful life can be enriched. If the hates and conflicts of the past continue in the present age, man may destroy his world. The destructive power of atomic energy has made the earth too small a place to hold both man and his hatreds.

What are the keys that scientists have used to unlock the tightly closed doors leading into the atom's powerhouse? To answer this question, we must examine the building blocks — the chemical elements — of which everything in the universe is made. All matter is made up of various combinations of these elements, of which we now know ninety-eight. These simple substances — such as carbon, hydrogen, oxygen, iron, nitrogen — combine in many different ways to form the stars, the air, the sea, the earth and all the familiar objects that surround you every day. In fact, your own body is composed of chemical elements. The most complex substances can be broken down into these simple building blocks.

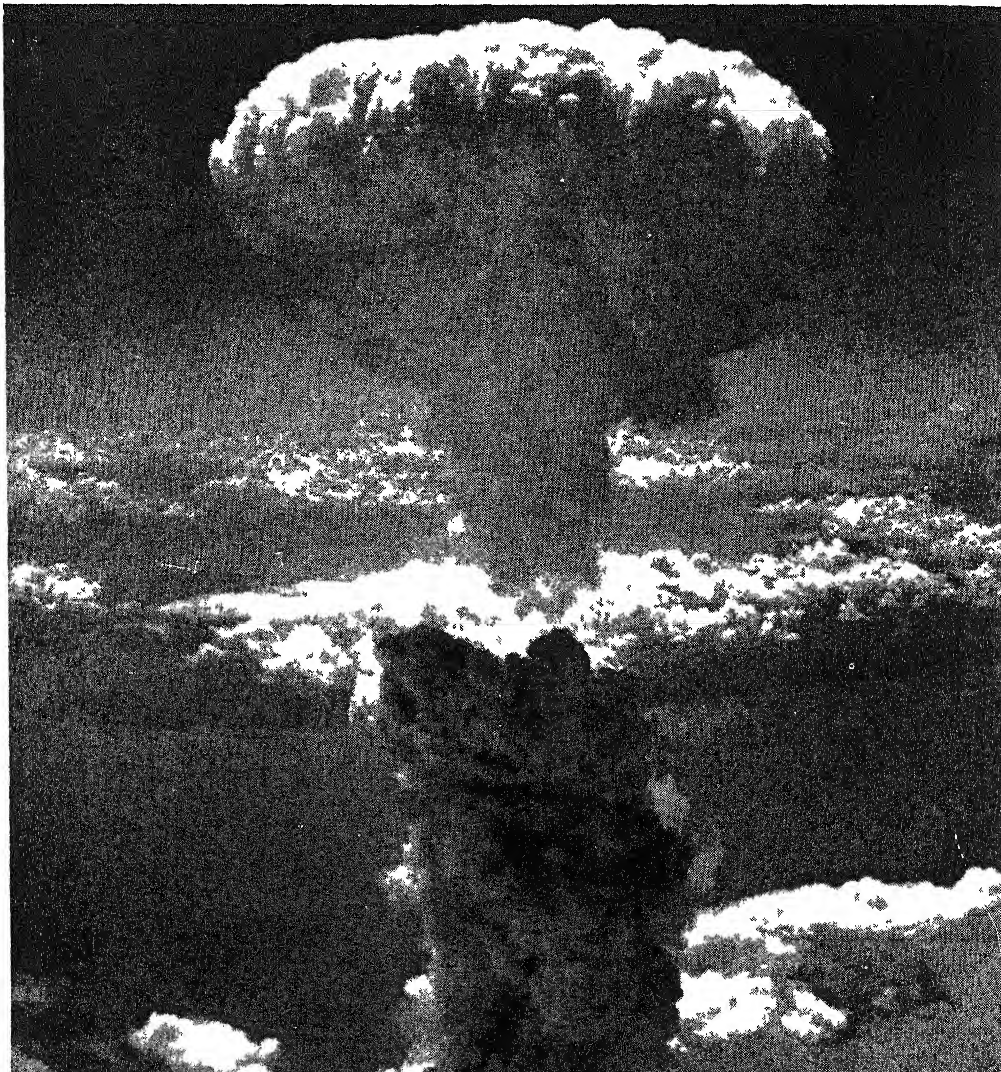
More than a hundred years ago, William Prout, an English chemist and doctor, suggested that nature's most complicated forms of matter could be chemically reduced to even simpler terms than those of the known elements. Prout believed that there was one basic element, hydrogen. He suggested that all the other elements were formed from combinations of hydrogen, the lightest and simplest of them. If he had been correct, it should have been possible to break down all the other elements, chemically, into some form of hydrogen. The world would have been a hydrogen world.

But Prout was mistaken. It proved impossible to break down any of the other elements chemically into simpler forms because they were already nature's simplest chemical building blocks. Chemical reactions change only the outer parts of atoms and do not reach into the atomic nucleus or center. It is possible to change one element into another only when a change occurs in the atomic nucleus; this is never possible by the use of chemical methods.

Hundreds of years before Prout's time, men in various parts of the world had tried to do much the same sort of thing that he proposed. These men were called alchemists, and they believed that it was possible to change one element into another — to turn other metals, not into hydrogen, but into gold. Indeed, they thought that all other metals were simply impure gold. Because everyone wished to have more gold, there was great interest in the "science" of alchemy, the forerunner of our modern science, chemistry. But the alchemists never succeeded in turning other metals into actual gold.

In order to understand better the problems faced by those who would hange one element into another, let us examine a typical specimen of matter — say, a liquid like water. Water, like all other substances, is made up of particles called molecules. These particles are too small to be seen with the ordinary microscope. Each molecule of water is a combination of several smaller particles called atoms. The chemi-

cal formula for water is H_2O, which says, in symbols, that a molecule of water contains two atoms of hydrogen and one of oxygen. Sometimes chemical formulas are written in a way that shows the actual arrangement of the atoms as they cluster together to form a molecule. The formula for water could be written HOH, to show that one oxygen (O) atom is linked with each one of the two hydrogen (H) atoms



U S Army A A F

The atomic-bomb explosion that took place at Nagasaki, Japan, on August 8, 1945. This was the third atomic-bomb blast in the history of mankind. The first one, which resulted from the fission (splitting) of uranium atoms, was set off in a desert area of New Mexico on July 16, 1945. The explosion vaporized the steel tower on which the bomb had been hung, made the desert sands radioactive and proved that the atomic bomb was not a scientist's dream but a grim actuality. On August 5, a United States plane dropped another uranium bomb on the Japanese city of Hiroshima. It brought about fearful havoc; it killed 60,000 persons outright, wounded 100,000 others and destroyed over half the city. The bomb that fell on Nagasaki three days later was a plutonium bomb; it flattened a square mile of the city and took a heavy toll of life. These two bombs destroyed Japan's will to resist. They had reduced acres of buildings to rubble with a blast that dwarfed any man-made explosion ever produced on the earth before this; they had released deadly radioactivity; their heat had seared the surroundings.

that are found in every water molecule.

The structure of the atom can be thought of as something like the system of the sun and the planets, a miniature solar system. There are, however, certain very important differences. In the first place, the "planetary system" of an atom is held together by electrical forces, not by the forces of gravitation which control the bodies of the solar system. Also, the atomic "sun," the nucleus of the atom, is very tiny compared to the "planets," whereas the sun is the largest object in the solar system.

The nucleus is the "sun" of the atomic "solar system"

At the center of the atom is the tiny nucleus which, despite its size, contains nearly all the mass and weight of the atom. The diameter of a typical atomic nucleus is about one millionth of a millionth of an inch. The "planets" of the atomic solar system are particles called electrons which revolve at very high speeds around the nucleus. Considering the size of the atom as a whole, the distance of the electrons from the nucleus is tremendous. It is much greater in proportion than the distances of the real planets from the sun. We can perhaps get a better idea of the relatively enormous spaces within the atom by imagining a large-scale picture of a hydrogen atom, as did the great English physicist Sir Ernest Rutherford. Let us imagine the nucleus as about the size of a pea, instead of an object one millionth of a millionth of an inch across. We shall then have to place the one electron of the hydrogen atom 300 miles away from the nucleus. This electron, while its mass is only 1/1835 of the mass of the nucleus, would in our picture be about 30 feet in diameter. Because of the great distances of the electrons from the nuclei of atoms, we sometimes say that solid matter is mostly empty space.

The physicist — the student of modern physics — has probed deep within the atomic nucleus. By utilizing new tools and methods he has succeeded in transmuting elements (changing one into another); thus he has become the modern alchemist. We shall call the processes by which the physicist brings these changes about *alchemical reactions*, to distinguish them from chemical reactions or changes. The alchemical reactions are also called *transmutations*.

How alchemical processes differ from those of chemistry

The methods and tools of modern alchemy are very different from those of chemistry. The chemist can make elements combine to form a compound — a combination of atoms — as when hydrogen burns in oxygen to produce water. When this happens, energy is freed in the form of heat. The chemist can also separate compounds into the elements of which they are composed. He can decompose water into hydrogen and oxygen. In this process energy is not freed, but must be supplied in the form of heat to make the reaction go. Sometimes, then, chemical reactions free energy and sometimes they use it up.

The physicist, in alchemical processes, works with the atoms of a chemical element. In a sense, this is what the chemist does, too. But the chemist is interested mainly in the behavior of atoms as they take part in the building up and breaking down of compounds The core of the atom itself is never changed in such chemical reactions. The nuclear physicist, on the other hand, may combine atoms of simple elements to form atoms of more complicated elements; he may break down the atoms of an element into simpler atoms belonging to another element. Just as in chemical processes, energy is sometimes set free and sometimes used up. Whichever happens, the amounts of energy concerned in alchemical reactions are millions of times greater, atom for atom, than they are in chemical processes.

We have seen that the chemist can combine elements into new compounds (combinations of elements). Many of these, such as nylon and the plastics, for instance, have never been found in nature. The physicist, too, can create new substances by alchemical reactions — new elements that have never been seen before, some of which do not exist in a natural state.

Each one of the 98 known elements has its own special kind of atom. One of the important properties, or characteristics, of an atom is its atomic weight. You may very well ask how such a tiny thing as an atom, which no one has ever seen, can be weighed. As a matter of fact, no one has ever been able to weigh an atom directly. Atomic weight is a relative or comparative thing. Chemists have been able, by intricate methods, to determine how much heavier the atoms of one element are than the atoms of another. But we can not say that an atom weighs so many units of weight, as we can say that a package of butter weighs half a pound. We can say with certainty, however, that an atom of one element weighs two, three or ten times as much as an atom of another element.

The atomic number of an element is connected with its atomic weight

Another important property of an element is its atomic number, which is directly connected with its atomic weight. Hydrogen, with the lowest atomic weight, has atomic number 1. Helium, with the next lowest atomic weight, has atomic number 2, and so on, up to the element with the greatest atomic weight, at the end of the list.

Here is a list of some of the more familiar chemical elements. The symbols which the chemist uses for them, their atomic numbers and their atomic weights are also given.

Some of the Chemical Elements

Element	*Symbol*	*Atomic Number*	*Atomic Weight*
Hydrogen	H	1	1.008
Helium	He	2	4.003
Beryllium	Be	4	9.02
Boron	B	5	10.82
Carbon	C	6	12.01
Nitrogen	N	7	14.008
Oxygen	O	8	16.00
Fluorine	F	9	19.00
Sodium	Na	11	22.997
Aluminum	Al	13	26.97
Phosphorus	P	15	30.98
Sulfur	S	16	32.06
Chlorine	Cl	17	35.457
Potassium	K	19	39.096
Calcium	Ca	20	40.08
Iron	Fe	26	55.85
Nickel	Ni	28	58.69
Copper	Cu	29	63.57
Bromine	Br	35	79.916
Silver	Ag	47	107.880
Tin	Sn	50	118.70
Iodine	I	53	126.92
Wolfram (tungsten)	W	74	183.92
Mercury	Hg	80	200.61
Lead	Pb	82	207.21
Radium	Ra	88	226.05
Thorium	Th	90	232.12
Uranium	U	92	238.07

By examining these figures, we can tell, of course, how much heavier or lighter each element is than any other element. For example, we know that oxygen, with the atomic weight of 16.00, must be about 16 times as heavy as hydrogen (atomic weight 1.008) and about 4 times as heavy as helium (atomic weight 4.003).

The periodic table of the elements, as developed by Dmitri Mendeleev

About 1870, the Russian chemist Dmitri Mendeleev arranged the chemical elements in an interesting list, known as the periodic table, which is of the greatest value, not only to the chemist, but to the modern physicist as well. Mendeleev arranged the elements in the usual order of atomic number and atomic weight. But he also divided them into eight large groups or columns. In each of the eight columns are placed the elements that behave somewhat alike chemically.

Not all the atoms of some elements are exactly alike; not all hydrogen atoms are alike, for instance. The atoms of a given chemical element may differ in their atomic weights; but their chemical properties are always identical. Atoms that differ in atomic weight, but not in chemical properties, are called isotopes. The atomic weight of an element, as it is given in our list or in the periodic table, is the average of the

weights of its various isotopes. The atomic weight of the element chlorine, for example, is listed as 35.457, which is the average of the atomic weights of chlorine's two isotopes.

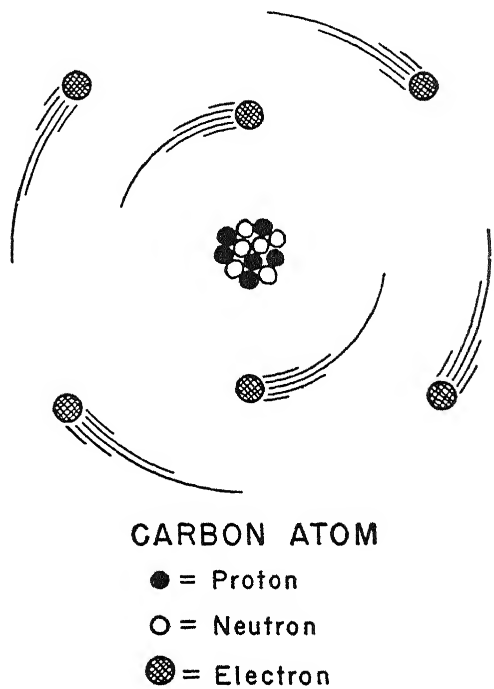
The atomic weight of an isotope is known, not as atomic weight, but as *mass number*. This term is used to keep us, when we are speaking of atomic weight, from mixing up the atomic weight of the element, which is just an average value, and the actual atomic weights of the isotopes. We shall use the term mass number to mean the whole number that is nearest to the exact atomic weight of any isotope.

The physicists who deal with alchemical reactions have developed a kind of shorthand to indicate the atomic number and mass number of a given isotope. They give the chemical symbol of the element in question; they put the atomic number in front of and below the symbol and the mass number after and above it. Thus $_8O^{16}$ stands for oxygen with atomic number 8 and mass number 16. For the chemist there are only 98 atomic species, or types, that are different from each other. Isotopes show the same chemical behavior, however they may differ in mass number, and therefore there is no reason for the chemist to distinguish between isotopes. He is interested only in chemical behavior.

The physicist, however, is concerned in his alchemical studies with both atomic number and mass number. Isotopes of a chemical element may differ greatly in their alchemical properties, even though they have the same chemical properties and the same atomic number. There are many more isotopes than elements, since many elements have several isotopes each. Because of this, the physicist has to consider several hundred different kinds of atoms found in nature.

We already know that the atom is held together by electrical forces. Most of the separate particles that make up the atom carry electrical charges. The nucleus itself carries a positive electrical charge. The amount of this charge is indicated by the atomic number and is equal in quantity to the total electrical charge carried by the electrons. The charge carried by the electrons, however, is negative.

Normally, the atoms of matter are electrically neutral. The positive charge of the nucleus is neutralized or made inactive by an equal amount of negative electricity present elsewhere in the atom — in the electrons. Sometimes an atom may, under spe-



A greatly simplified and necessarily distorted diagram of a carbon atom Since the nucleus contains six protons and a total of twelve protons and neutrons, the atomic number of the carbon atom is six and its atomic weight is twelve. Note the six electrons revolving around the nucleus.

cial circumstances, lose an electron to another atom. It will then, since it has lost one of its units of negative electricity, be positively charged. It may, on the other hand, capture an electron from another atom. It will then be negatively charged instead of neutral. Atoms that have lost or gained an electron, so that they are no longer electrically neutral, are known as ions.

The number of electrons moving around the nucleus of an electrically neutral atom is just equal to the atomic number. Thus, the atom of hydrogen has one electron, since the atomic number of hydrogen is

one. The atom of uranium, with atomic number 92, has 92 electrons.

The chemical behavior of any given atom is determined by the number and arrangement of the electrons. Chemical changes, as we have seen, involve only minor rearrangements in the outer electrons of an atom and never alter the atom's inner structure; they never involve a change in atomic number, or mass number.

Transmutation of the elements can occur only when there is a change in the atomic number of the atom. Such a change would, of course, alter the amount of positive charge of the nucleus. When one isotope is changed into another, there is a change in the mass number of the atom, but not in the atomic number. Any of these changes bring about an alteration in the nucleus.

The nuclei of all atoms are built of the same kinds of particles

If we can change atomic nuclei into one another, it must be because these nuclei are all built of the same kinds of particles. Such is the case. One of these nuclear particles is called the proton. Its weight is about one on the atomic-weight scale. Its electrical charge is positive (the protons carry the positive electrical charge of the nucleus). Its electrical charge is also equal in quantity to the negative charge of one electron. Thus, the proton has atomic number 1 and mass number 1.

The nucleus of the lightest and simplest of all atoms — that of hydrogen — is composed of one proton. The hydrogen atom, therefore, has atomic weight 1 and atomic number 1.

The second basic particle of the nucleus is called the neutron. Its mass is almost exactly that of the proton and its electrical charge is zero. It is called the neutron because it is electrically neutral.

All nuclei, except that of hydrogen atoms, are made up of protons and neutrons and some other very tiny particles. The number of protons, in each case, is the same as the atomic number and the number of electrons. The number of neutrons is equal to the mass number minus the atomic number. (Another way of putting it is that the number of protons plus the number of neutrons gives the mass number.) You will notice, by referring to the list of elements, that in the case of the lightest elements, through calcium (atomic number 20), the atomic weights are just about twice the atomic numbers. This is another way of saying that these light nuclei contain about equal numbers of protons and neutrons.

Now let us examine a special kind of atom. Some of the atoms found in nature are unstable. This means that their nuclei give off particles or rays, or both, and break up, of their own accord, forming atoms of other elements. This type of atom is called radioactive, after the element radium, the most familiar example of this kind. The atoms of radium have the mass number 226 and the atomic number 88. About 37,000,000,000 atoms of one gram of radium transform themselves each second into another element called radon. Radon's mass number is 222 and its atomic number is 86. It differs from radium by four mass units and two units of atomic number, as you can see. Since we know that these four mass units and two units of atomic number can not just have disappeared, we must try to find out where they are.

Alpha particles — helium nuclei — are shot out when radium breaks up

What kind of atom has a nucleus that represents this difference? The answer is — the helium atom, for it has the atomic number 2 and the mass number 4. And, indeed, a careful study of the particles emitted in the breaking-up of radium shows that these outgoing particles are the nuclei of helium atoms. When an atom of radium breaks up, its nucleus shoots out this helium nucleus — which is called an alpha particle — with great speed. The nucleus left behind is a nucleus of the gas radon. An atom of the ordinary-looking, silver-gray metal, radium, has transformed itself spontaneously into two gas atoms — one of helium and one of radon.

The alpha particle that is fired out of the radium nucleus carries away quite a lot of energy in the form of motion. As it

leaves the nucleus, its speed is more than 9,000 miles a second. It is brought to rest because of its many collisions with the atoms of oxygen and nitrogen of the air through which it travels, or with the atoms of other substances in its path. In each

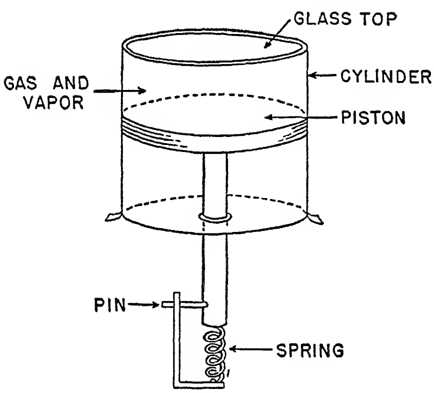
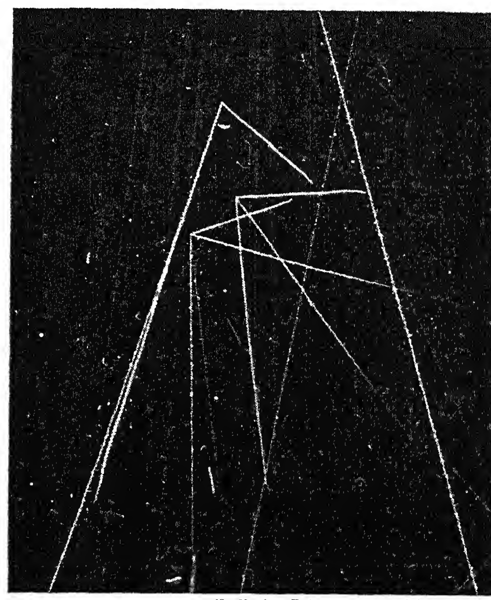


Diagram of a Wilson cloud chamber. If the pin is pulled to the left, the spring is released and quickly pulls down the piston in the chamber. The gas and vapor then expand and therefore cool.

such collision, the alpha particle spends a small part of its energy in knocking some of the outer electrons from the atom it has struck. It loses a part of its speed in this way. In ordinary air, an alpha particle from radium will travel about an inch and a quarter before it is completely stopped. Since the alpha particle loses such a small fraction of its energy in each encounter with an atom, it is deflected very little from its straight path. It therefore travels in very nearly a straight line from its start in the radioactive atom to the point at which it is finally stopped.

We can see the path of an alpha particle in a device called the cloud chamber. This is a chamber in which a mass of gas saturated with water vapor can be rapidly cooled. As the gas cools, the vapor condenses in the form of droplets. If there are electrically charged atoms in the gas of the cloud chamber, the water droplets will condense on these charged atoms before they can be seen anywhere else in the chamber. By careful control of the cooling of the gas, the droplets can be made to condense *only* on the charged atoms. An alpha particle, as it travels, leaves behind it a trail of atoms whose outer electrons have been knocked off; some of the electrons freed in this way are left behind, also. A little line of fog or water droplets that have condensed on these particles marks the passage of an alpha particle through a cloud chamber.

As we have said, about 37,000,000,000 atoms per gram of radium transform themselves into radon and helium each second. There are so immensely many atoms altogether in a gram of radium — about 2,500 million million million — that it takes 1,690 years for half of any given quantity of radium to decay into radon. In another 1,690 years only half of the remainder, or one quarter of the original quantity, will be left, and so on. The time required for half of a given amount of radioactive material to transform itself is called the *half life* of the material. This is an important property of a radioactive substance. The radioactive atoms found in nature have



Radiation Laboratory of Univ. of Cal.

This photograph shows how oxygen atoms are broken up by fast neutrons in a Wilson cloud chamber. About 300,000 neutrons have swept across the chamber from the top to the bottom of the picture in a beam ⅝ of an inch in diameter. The long straight tracks are those of atoms that have been knocked out of the glass walls of the chamber. Three atoms of oxygen are shown breaking apart.

half lives ranging from about one one-hundred-thousandth of a millionth of a second to several billion years.

The beta particles emitted from a radioactive nucleus are electrons

There is another type of radioactive decay. This has to do with the emission of so-called beta particles. These are simple, ordinary electrons expelled from the nucleus with great speed. (Here you are perhaps remembering that electrons are *outside* the nucleus, and wondering how an electron could be expelled *from* the nucleus. We shall take up this question a little later on.) Since the mass of an electron is only about 1/2000 of one unit of mass number, the emission of a beta particle does not change the mass number of a radioactive nucleus. However, the emission of a beta particle, carrying a negative charge of one unit away from the nucleus, does increase the positive charge on the nucleus (and therefore the atomic number of the atom) by one unit.

And now let us examine the case of the negative electron that is, strangely enough, emitted from a radioactive nucleus. How, if the nucleus is made up only of protons and neutrons, can it shoot out an electron? Must there not, then, be electrons in the nucleus? According to our present ideas, the electrons shot out of the nucleus as beta particles are not previously present in the nucleus. They are created at the moment when they are emitted. George Gamow, a nuclear physicist who has made many contributions to our present understanding of radioactivity, puts it this way: "Electrons do not exist inside the nuclei before they are emitted, just as soap bubbles do not exist inside a pipe before they are blown out" Remember that we are speaking here only of electrons *inside* the nucleus. There is not the slightest doubt that the exterior structure of an atom, outside the nucleus, is made up entirely of electrons.

Only the heaviest elements found on earth are naturally radioactive. The process of radioactivity transmutes heavier atoms into lighter ones. As the final step in such a process, an atom of uranium or thorium becomes an atom of lead, with the creation of several atoms of helium along the way Once natural radioactivity had been discovered, scientists began to wonder whether such reactions could be produced under controlled conditions in the laboratory.

They even wondered if they might be able to reverse the process of natural radioactivity. If radium emits an alpha particle and turns into radon, might it not be possible to shoot alpha particles into radon and change some of the radon back into radium? Experiments were made, but they were failures.

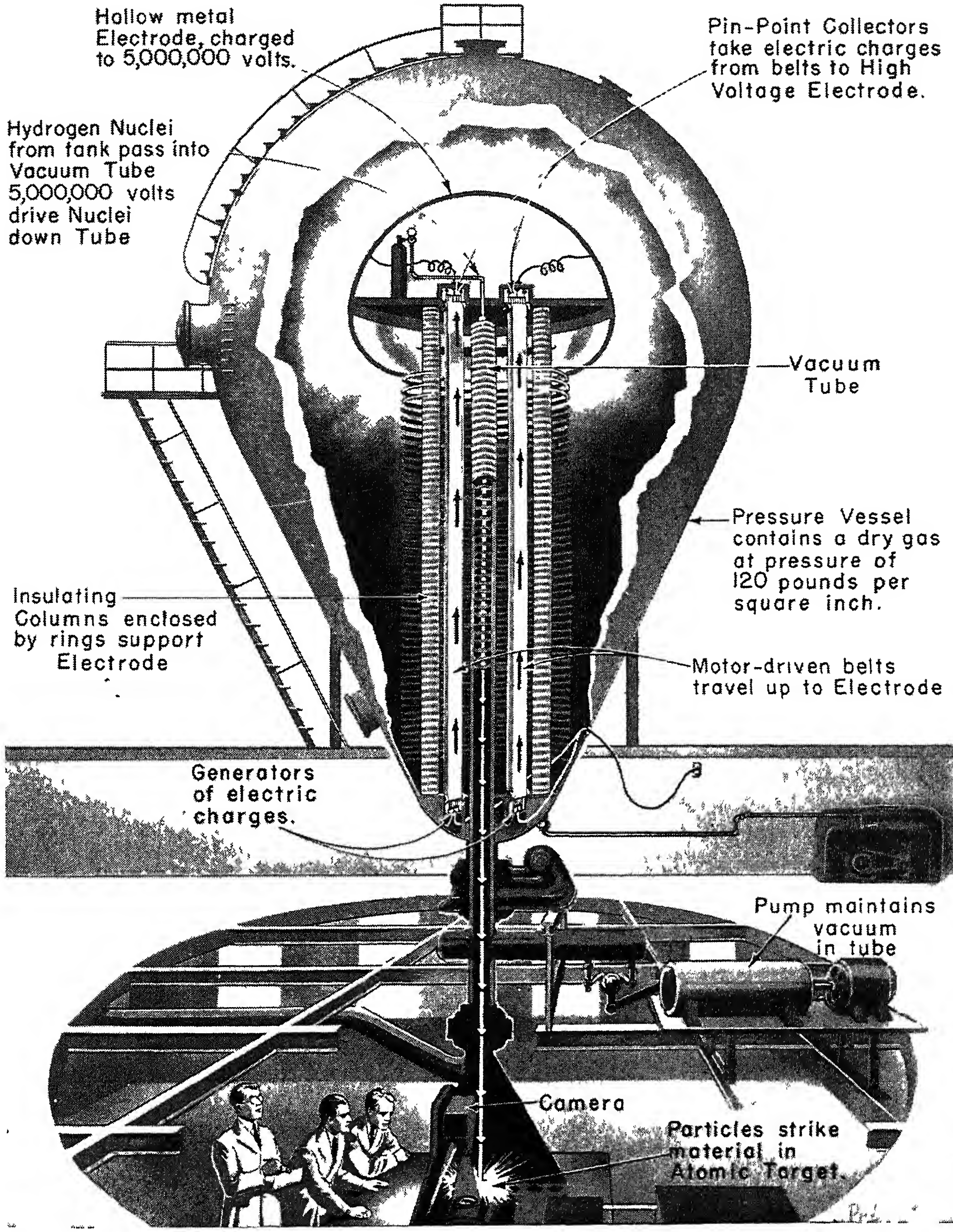
When the lightest elements were bombarded with alpha particles, however, there could be no doubt that they were undergoing alchemical changes. The first experiments of this kind were made by Sir Ernest Rutherford in 1919. Rutherford bombarded atoms of nitrogen (mass number 14) in the cloud chamber with alpha particles -- nuclei of helium atoms (mass number 4). A proton was knocked out of the nitrogen atom, leaving it with mass number 13; but an alpha particle took its place raising the mass number to 17. As a result of this transmutation the nitrogen had been changed to a proton — the nucleus of a hydrogen atom (mass number 1) — and an atom with mass number 17. The latter was no longer a nitrogen atom but a rare isotope of oxygen. (Oxygen has atomic weight 16.00.)

After the discovery by Rutherford that light atoms could be transmuted by bombarding them with alpha particles, a careful study of such alchemical reactions was made. It was found that most of the light atoms could be transformed in such reactions, where an alpha particle is absorbed and a proton emitted.

Neutrons are shot out when beryllium is bombarded with alpha particles

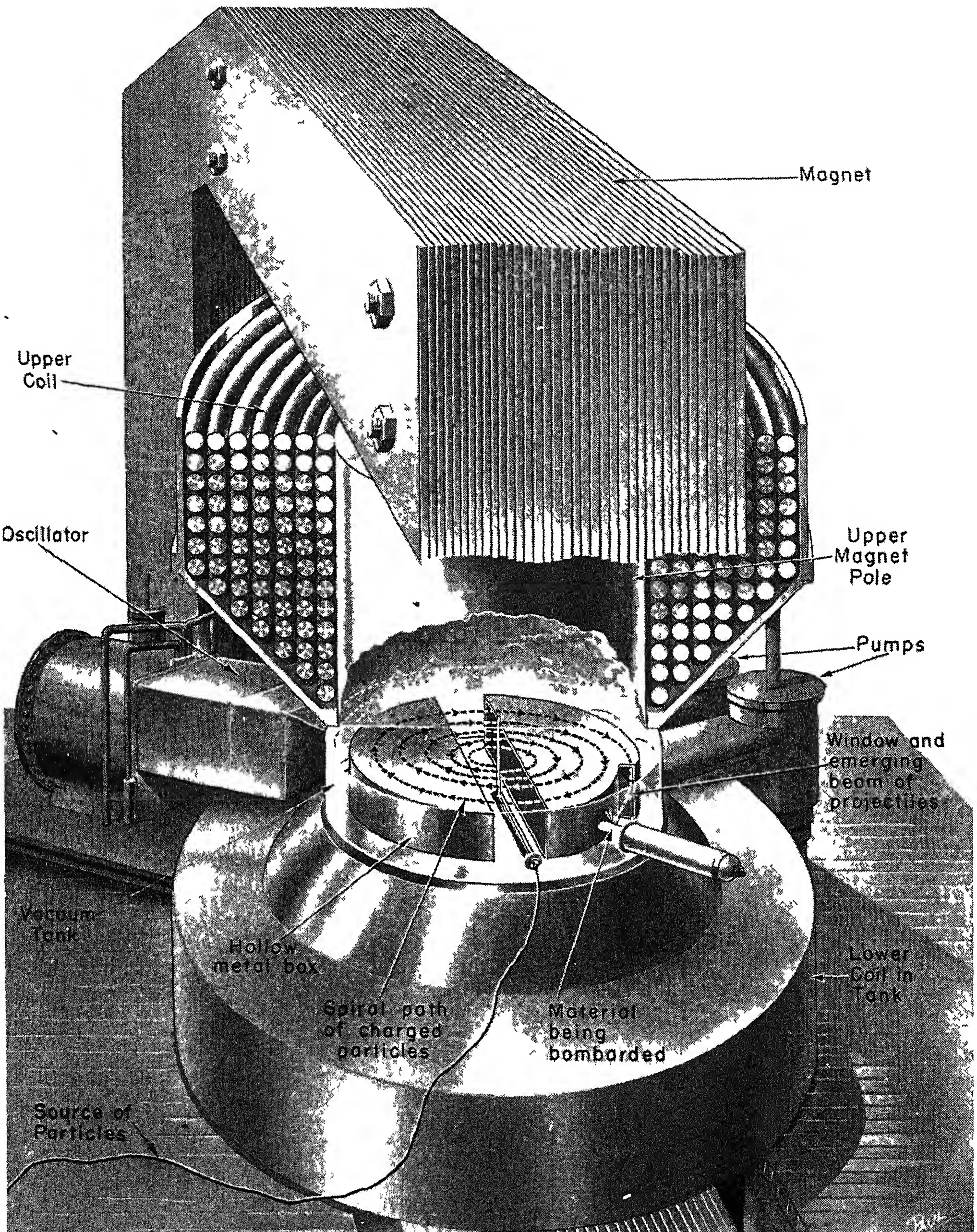
Another type of reaction was discovered in 1932. By bombarding the element beryllium with alpha particles, particles were shot out that could go through great thicknesses of heavy elements without being very much absorbed. These particles.

THE ATOM-SMASHER OF VAN DE GRAAFF



This atom-smasher, developed by R. J. Van de Graaff, is called an electrostatic generator. The pear-shaped tank in which the apparatus is enclosed is filled with air under pressure or with insulating gas; this makes it possible to bring about higher voltages than in the open air. The hollow metal electrode at the top — the cap — is supported by insulating columns. Running down from the cap are the charging belts. A source of electricity sprays charges on to the belts; these carry the charges to the cap and cause the cap itself to be charged. A vacuum tube extends from within the cap to the bottom of the apparatus. Atomic "bullets" shoot down this tube, driven by the great electric forces between the charged cap and the ground. The "bullets" then smash into the material serving as a target.

THE CYCLOTRON — A MIGHTY ATOM-SMASHER



In the cyclotron the electrodes consist of two hollow half-cylinders, called "dees" (D's) because of their shape. They are set in a vacuum tank between the poles of a powerful electromagnet. Ions — charged particles — are producd at the center of the small gap between the dees. As long as the ions are in the gap, they are attracted to one or another of the two charged dees. As an ion enters the hollow space in the dee, the magnetic field of the big magnet curves the ion path circularly. Back in the gap, the ion is pulled into the other dee because the electric oscillator has reversed the charges on the dees in the meantime. This process is repeated many times per second, the ions moving in widening circles. At last they reach the outer part of a dee, emerge from a window and strike the target.

however, could be absorbed in relatively short distances by substances containing hydrogen, such as paraffin, wood or water. This particle proved to have a mass almost exactly the same as that of the proton, and no electric charge. It proved, of course, to be the neutron.

Since the neutron has no electrical charge, it is not affected by the negatively charged electrons making up the outer structure of the atom. When it comes very close to an atomic nucleus, however, the neutron exerts strong force on the protons and neutrons making up the nucleus. For this reason it is an ideal "bullet" for bombarding atomic nuclei to produce alchemical reactions. It does not fritter away its energy as a charged particle does, by making fruitless collisions with the outer electrons of an atom. The neutron loses its energy only when it collides with an atomic nucleus. Not every such collision, however, results in an alchemical reaction. Often the neutron will merely bounce off the nucleus it has struck, giving part of its energy of motion to that nucleus.

And now let us look for a moment at a very important principle that has to do with alchemical reactions — the Law of Mass-Energy Conservation. This law applies directly to Rutherford's experiments and to the bombarding of beryllium with alpha particles.

In atomic research, one must consider the relation between mass and energy

The relation between mass and energy is of vital importance to the nuclear physicist. Mass and energy appear to be two different aspects of the same fundamental thing. Mass can be turned into energy, and energy can be turned into mass. If a change in mass is produced in an alchemical reaction, the energy equivalent of the mass that has appeared or disappeared must turn up somewhere as a result of the reaction.

These mass-energy relations show us the immense importance of the fact that the exact atomic masses of most isotopes are not quite whole numbers. By comparing the exact atomic masses of the elements entering in alchemical reaction with the exact atomic masses of the elements produced in the reaction, we can tell whether energy is set free or used up in the process.

The two types of reactions that provide atomic energy

If we wish to obtain energy from alchemical reactions, we should use either a reaction in which the lightest atoms combine to form heavier ones, or a reaction in which the heaviest atoms split up into lighter ones. Both types of reaction are now known. As we shall see, a light-atom reaction is responsible for producing the the energy of the sun, while a heavy-atom reaction produces energy for the atomic bomb.

In their study of alchemical reactions, physicists found themselves severely handicapped so long as they had only alpha particles from radioactive elements to use as bullets for breaking up atomic nuclei. Particles from even the strongest radioactive sources broke up only a few nuclei per second. And this was far from enough for the experimental study of alchemical reactions. What was needed was a stronger and faster bullet that would be sure to penetrate the atom's electrical field and enter the nucleus of the target atom. Because of this, scientists were very much interested in the development of devices that would greatly speed up the atomic bullets used in the process of changing one element into another.

One of the earlier devices of this kind was the electrostatic generator. In this instrument, protons or other charged particles are speeded up enormously and are then shot through a vacuum at an atomic target. In the diagram on page 1433 we show you how the electrostatic generator works.

The cyclotron is one of the most successful of devices for speeding up atomic bullets. (See diagram on page 1434.) It is widely used in producing high-energy particles for experiments in transmutation. In the cyclotron the atomic bullets move through magnetic fields, speeded up in-

creasingly by traveling through areas of low-voltage electricity many times. Eventually enough force is built up to propel the bullets at enormous speeds. They can then be successfully aimed at the target atoms. The cyclotron can be used to produce a beam of high-speed particles, or it can speed up protons or the nuclei of the heavy isotope of hydrogen. (These nuclei, called deuterons, consist of one proton and one neutron. This nucleus has mass number 2.)

Why protons and deuterons make better "bullets" than alpha particles

Because they have a smaller electrical charge than alpha particles, protons and deuterons are repelled less strongly by the like electric charge on the nucleus that is their target. Protons and deuterons are therefore somewhat more effective than alpha particles as atomic bullets. Further, the cyclotron and the other devices for producing high-speed atomic projectiles (such as the linear accelerator, the synchrotron and others) can make beams of such particles that are many times as intense as any that could be produced by available radioactive sources.

With the help of these new techniques, many different alchemical reactions were discovered in the years between 1932 and 1940. In particular, it was found that the atoms formed in an atomic transmutation are not always stable types that exist in nature. Sometimes they are unstable (radioactive) isotopes of known chemical elements. This process of creating new radioactive substances is called "artificial radioactivity." It is artificial only in the sense that the new isotopes do not exist in nature, but are made in the laboratory.

Artificial radioactivity was discovered in 1934 by Irène Joliot-Curie, the daughter of Marie Curie, and her husband, Frédéric Joliot-Curie. There is no important distinction between the natural and the artificial radioactive elements. For example, polonium, a natural radioactive element, discovered by Marie Curie, can also be made in the laboratory.

It is interesting that many of the radioactive atoms made in the laboratory emit positrons in their decay. (Positrons are positive electrons.) There is no reason to suppose that positrons are parts of atomic nuclei. This gives us some confidence that the electrons emitted in radioactive decay do not exist in the nucleus before they are shot out.

The stable types found in nature (those that do not break up by radioactivity into other elements) appear to be the *only* stable types. When we make other types of atoms — isotopes of known elements — that do not have the atomic number and mass number of a known isotope, we find that the atoms we have made are radioactive.

Many types of unstable atoms can be made by bombarding the atoms of various elements with neutrons. For example, when iodine is bombarded with neutrons, radioactive iodine is formed, iodine 128 (that is iodine of mass number 128). This isotope emits negative electrons, turning into xenon 128, a stable isotope of xenon.

The great Italian physicist Enrico Fermi once asked himself, "What will happen if we bombard the element uranium with neutrons? Uranium has the highest atomic number known [this was true at that time] — number 92. If we can produce a radioactive isotope of uranium that emits negative electrons, this will mean that it is transforming itself into an element of atomic number 93. No such element is known on earth."

Producing radioactive substances by bombarding uranium with neutrons

The experiment was immediately tried. Fermi found that he could produce, not one, but several different radioactive substances by bombarding uranium with neutrons. These substances all had different half lives. It was very difficult to sort out and identify the various kinds, and Fermi did not succeed in doing so completely when he tried the experiment. He did find evidence that at least one of the radioactive species was an isotope of uranium. This isotope was turning into element 93.

It was very puzzling, however, that so

many different radioactive species could be produced by bombarding uranium with neutrons. Late in 1938, it was discovered that one of the radioactive types produced in this way was an isotope of the element barium. This discovery may not sound very exciting, but it was the single clue that led, less than seven years later, to the atomic bomb.

Barium has atomic number 56, while uranium has atomic number 92. The uranium nucleus, after capturing a neutron, split itself into two almost equal parts. (This splitting of a nucleus is called *fission.*) If one of these parts is barium, of atomic number 56, then the other part must have the atomic number 92 minus 56 — or 36. The element of atomic number 36 is the gas krypton. Such a splitting of a heavy nucleus liberates a tremendous amount of energy. Measurements show that the energy freed in the fission of the uranium nucleus is more than ten times as great as the biggest amount of energy set free in any other alchemical reaction known at the time fission was discovered.

Why neutrons are emitted when U^{235} atoms split apart

The two lighter atoms produced by the fission of a uranium atom must have mass numbers that add up to the mass number of the uranium before fission. As we shall see, uranium 235 is the isotope of uranium most important in the fission reaction. When it captures a neutron, it becomes U^{236}, which immediately splits apart. Now the heaviest stable atom of barium has the mass number 138, while the heaviest stable atom of krypton has the mass number 86. The sum of these numbers is 224, 12 less than 236. Thus the fission fragments have, between them, 12 more neutrons than stable isotopes of the fragments would have. We can predict, then, that some of these neutrons will be emitted, either in the fission process itself or shortly afterward. Fission does not always yield fragments that are atoms of barium and krypton. The uranium atom divides into two slightly unequal parts in any of several different ways.

Neutrons, as we have just seen, cause the fission process in the first place. They are our bullets to start the reaction. Since they are also shot out in the fission process, it is possible that they will keep an alchemical "fire" going, once it is started. If we shoot a few neutrons into a lump of uranium, the fissions so produced will yield more neutrons. These neutrons will produce more fissions. These fissions will yield more neutrons, and so on and so on. This process is known as a chain reaction.

Alchemical "fires" may reach temperatures of millions of degrees

Each fission liberates energy. Our alchemical "fire" will rapidly grow very hot. The "fires" that took place over Hiroshima and Nagasaki reached the incredible temperature of several tens of millions of degrees. This temperature is about the same and possibly even greater than that at the very center of a star like our sun.

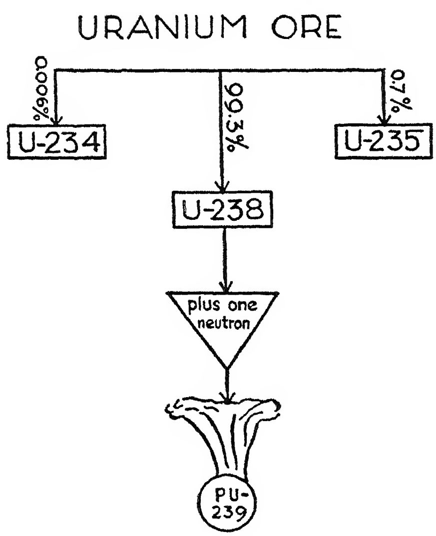
There are very serious difficulties in the actual production of an atomic "fire." To understand some of them we must look a little more closely at the details of the processes that occur when we bombard the heaviest elements with neutrons.

U^{235} (uranium of mass number 235) fissions much more readily than U^{238}. (The other isotope found in natural uranium, U^{234}, is so very rare that it is of no importance in atomic fission.) U^{238} usually captures neutrons without producing more neutrons as a result of fission. Since there is about 140 times as much U^{238} as there is U^{235} in natural uranium, this tendency of U^{238} to gobble up neutrons is very important. In fact, because of it, it is impossible to start a nuclear "fire" in a single lump of natural uranium. The extremely rich deposits of uranium ore occurring in Canada and the Belgian Congo would have burned up long ago if a "fire" could take place in somewhat diluted natural uranium.

The most direct way to make a nuclear fire is to separate the fuel, U^{235}, from natural uranium. Before the second World War, the only successful large-scale separation of isotopes of a chemical element was that of light hydrogen (mass number

1) from heavy hydrogen (mass number 2), accomplished by Dr. Harold C. Urey. This is the easiest of all isotope separations, because the heavy hydrogen weighs twice as much as the light hydrogen and the difference in physical properties of the two isotopes is quite marked. The job is much harder in the case of uranium, for the difference in mass is only three parts in 235, or less than 2 per cent. Of course, no separation of isotopes by chemical means is possible, for isotopes have, as we have seen, the same chemical behavior.

In spite of the obvious difficulty of separating the uranium isotopes on a large enough scale to yield pounds of pure U^{235}, the job was undertaken as part of the wartime atomic-energy project. Let us examine the two most successful methods used.



This diagram shows the relative proportion of the three isotopes of uranium, with mass weights respectively of 234, 235 and 238. U^{234} is so rare that it plays no part in the production of atomic energy. U^{235} was used for the bomb that devastated Hiroshima. The bomb that fell on Nagasaki contained plutonium, an element derived from U^{238}.

The path of a charged atomic particle flying through a vacuum can be bent by electric and magnetic fields. We can produce a stream of positively charged atoms of uranium by passing a strong electrical discharge through a vapor of uranium salts. This stream of charged atoms, or ions, will contain two types of uranium ions: those with mass number 235, and those with mass number 238. These two groups of uranium ions can be separated by passing the ion beam through suitably arranged electric and magnetic fields. The two separate beams of pure isotopes can be caught in separate collectors.

The chief difficulty with this method lies in producing an intense enough beam of uranium ions to yield practical amounts of U^{235} in a reasonably short time. The first model of the great electromagnetic separators that were set up at Oak Ridge during the war was built at Berkeley, California, by Professor E. O. Lawrence and his co-workers. To produce the necessary magnetic field, Lawrence used the giant 184-inch electromagnet that he had originally planned to use for a cyclotron. The Berkeley model produced only a millionth of a gram of U^{235} per hour. At this rate, it would take 50,000 years to produce one pound of pure U^{235}. Improvements in technique and the building of many separate units at the Oak Ridge plant greatly improved this result. As a matter of fact, the electromagnetic separation plant was the first to supply large quantities of U^{235} for use in the atomic bomb.

How U^{235} is separated by the gaseous diffusion method

The second method is known as separation by gaseous diffusion. The molecules of a gas do not have fixed positions relative to one another, as do the molecules of a solid. They do not even have the tendency to cluster together like the molecules of a liquid. Instead, the molecules of a gas dash independently about with very high speeds, colliding with one another and with the walls of the vessel containing the gas. Now, the speed that the molecules have, on the average, depends on the temperature. Their speed increases as the temperature rises. At any particular temperature, light molecules travel faster than heavier ones, since their speed is affected not only by increases in temperature but also by weight.

In the gaseous diffusion method, a barrier is set up — a wall pierced with billions

of holes about one-millionth of an inch in size. The barrier is placed between two chambers, one of which is a vacuum. The other chamber, separated from the vacuum chamber by the barrier, is filled with a gaseous compound of uranium and fluorine — uranium hexafluoride — UF_6. (The formula UF_6 indicates that in each uranium hexafluoride molecule there is one atom of uranium and six atoms of fluorine.) The gas uranium hexafluoride contains the two isotopes $U^{235}F_6$ and $U^{238}F_6$. The chamber that contains the gas is kept under normal pressure, but because of the difference of pressure in the two chambers, the molecules of gas tend to move toward the vacuum chamber through the holes in the barrier. The $U^{235}F_6$ molecules are lighter than those of $U^{238}F_6$. They therefore rush through the holes in the porous barrier with more speed. While more of the U^{235}-containing molecules get through into the vacuum chamber, many of those containing U^{238} also pass through. The gas in the vacuum chamber now, however, contains more of the desired U^{235} molecules.

This gas, with its greater number of U^{235} molecules, is collected, returned to normal pressure again, and once more passed through the barrier. With each trip through the barrier, the gas becomes richer in U^{235}. The process is repeated again and again — hundreds of times — in order to get U^{235} molecules that are pure enough for use in atomic bombs. In the Oak Ridge plant that was built to use this process, thousands of separate pumps, to create the vacuums, and acres of porous barriers were required. This immensely complicated plan was successful and produced quantities of U^{235} for atomic bombs.

Conditions that must be met if an atomic bomb is to be produced

Now that we know how one form of atomic explosive can be produced, let us look a little more closely at the problem of making an atomic bomb. In order to have a fission chain reaction that will keep itself going, we must be sure that each fission produces, on the average, more than the one neutron that it uses up. Then, too, the new neutrons formed by each fission must produce, on the average, another new fission. If we have too small a lump of U^{235}, the neutrons produced in a fission reaction may escape from the lump before they have produced another fission. Under these conditions, the fission chain can not keep itself going. When we take a larger lump of uranium, there is less chance for neutrons to escape without producing fission for they must, on the average, travel farther before they can get out

What is the critical mass of atomic explosive?

The amount of atomic explosive that will be required so that each fission reaction, on the average, will produce exactly one other fission reaction is called the critical mass of atomic explosive.

A mass smaller than critical can not explode. Any fissions that take place in it will, on the average, produce fewer fissions in each succeeding generation than there were in the one before. Because of this, the fission chain will die out. A mass larger than critical can not be kept from exploding, for if just one fission occurs, it will, in turn, produce more than one fission. Each successive generation of fission processes thus contains more members than the generation that went before. The reaction will go on with increasing violence. Finally the atomic explosive will be consumed or the heat that is generated will vaporize the lump and it will blow apart.

The problem of making an atomic bomb, then, involves creating suddenly the conditions that lead to an atomic explosion. If we have two or more masses of atomic explosive, each smaller than the critical mass, they can not explode so long as they are kept apart. If they are suddenly brought together to make a mass greater than critical, the result will be an atomic explosion. The time required for the atomic explosion is about half of a millionth of a second. We must bring the two or more less-than-critical masses together very rapidly in order to produce an efficient explosion.

We have already seen that a fission chain reaction can not be produced in a single piece of natural uranium. A chain reaction can be produced, however, in natural uranium by means of a trick of the physicist. This is how it is done.

U^{238} fissions only when it captures a neutron with considerable energy

To begin with, let us recall that U^{235} fissions readily and that U^{238} does not. U^{235} always fissions when it captures a neutron, even if the neutron is moving so slowly that it does not bring any energy of motion into the nucleus with it. U^{238}, on the other hand, will not quite fission when it captures such a "slow" neutron, although it will fission when it captures a neutron with a considerable amount of energy. When U^{238} captures a slow neutron, it turns into the radioactive U^{239}. It is because U^{238} absorbs neutrons without emitting others that chain reactions do not tend to occur in natural uranium.

Experiments have shown that U^{238} is most likely to capture neutrons and turn into U^{239} when the neutrons are moving at a particular speed. We can arrange things, however, so that the neutrons produced in the fission of U^{235} leave the uranium in which they are emitted and are slowed down in some other material. They can then re-enter the uranium with a speed so slow that they are not likely to be captured by U^{238}. When this happens, the U^{235} can compete more successfully with the U^{238} for the neutrons. In fact, as soon as we have really slow neutrons, the presence of U^{238} is no longer an obstacle to the capture of neutrons by U^{235}, in spite of the greater quantity of U^{238} in natural uranium.

But what are we to use as material for slowing down the neutrons produced in the fission of uranium? Lumps of natural uranium are embedded in a large mass of material capable of slowing down fast neutrons. This slowing-down material is called the moderator. It must be a substance that absorbs as small a number of neutrons as possible. It must also contain light elements, which are able to slow down neutrons most effectively. Heavy hydrogen, in the form of heavy water, is a good moderator, as is carbon in the form of graphite. The uranium lumps and the moderator are so arranged that fission neutrons escape from the uranium lump in which they are liberated before they have much chance of being captured. They are then slowed down well beyond the speed at which they could most easily be captured by U^{238}. Then they re-enter a lump of uranium and, when things go right, cause U^{235} to fission.

Such an arrangement of uranium lumps and moderator material — called a lattice — must be built up to a certain size before each fission will give rise to exactly one other fission. When the number of fissions produced is less than one to one, no continued or sustained reaction is possible. It dies out. When it is greater than one, the intensity of the reaction will increase indefinitely as time goes on. There is a critical size, then, for such a lattice, just as there is a critical mass for an atomic bomb.

The nuclear reactor or pile; what it is and what it does

This lattice arrangement of uranium and moderator is called a nuclear reactor or pile. A reactor of this kind is intended to operate under full control at all times. This means that the birth rate of fissions must be kept at exactly one to each parent fission, so that the level of power neither increases nor decreases. This birth rate can be controlled by moving into or out of the reactor adjustable graphite control rods which absorb neutrons. When these rods are inserted farther into the reactor, the birth rate of neutrons is decreased by the absorption of neutrons in the rods. When the rods are pulled farther out, the birth rate is increased.

Of course, it would be very difficult to control the reactor if it could "run away" and explode in half a millionth of a second, as an atomic bomb does. The neutrons emitted in the fission reaction, however, are not all shot forth at the same instant. A small fraction of them are emitted with delays that give enough time for the con-

trol rods to be moved. In uranium, one per cent of all fission neutrons are delayed by more than a hundredth of a second. One neutron in 1,400 is delayed by a minute or more. These delayed neutrons make the birth rate build up slowly enough so that it can be controlled by mechanically moved control rods.

This is all very interesting, you may be saying, but what has it to do with the atomic bomb? The answer is that another atomic explosive — plutonium (chemical symbol Pu) — can be made in such nuclear reactors. It was for this purpose that three great reactors were built at Hanford, Washington, as a part of the wartime atomic-energy project.

Plutonium is, in a sense, a by-product of the operation of a nuclear reactor that uses natural uranium. Plutonium 239 is formed, as a result of two successive radioactive transformations, from the U^{239} that is made when U^{238} captures neutrons. Pu^{239} is radioactive, emitting an alpha particle and becoming U^{235}; but Pu^{239} is relatively stable, since its half life is about 24,000 years. The fission properties of Pu^{239} are like those of U^{235}, not of U^{238}. It is therefore entirely possible to make an atomic bomb that uses plutonium as an explosive.

It is easier to prepare plutonium than it is to separate U^{235}

One may ask why we should go to all the trouble of making a nuclear reactor to manufacture a tiny quantity of plutonium that we must then separate from a much greater quantity of uranium. Why not separate U^{235} in the first place, and use it as an atomic explosive? The answer is that the separation of the two types of uranium can be accomplished only by one of the laborious methods that we have already described. Since plutonium is a different element from uranium, and has different chemical properties, it can be separated from uranium by the much easier methods of chemistry.

The possibility of making plutonium in a nuclear reactor was realized very early in the atomic-energy project. Fermi and his co-workers set out to construct a controlled-fission reactor on a small scale, first at Columbia University and then at the University of Chicago. The biggest problem was to get the uranium and the graphite pure enough, sufficiently free from small amounts of elements that would absorb neutrons strongly. On December 2, 1942, the first nuclear reactor was completed and set in operation. It worked at a maximum power level about equal to that of two medium-sized electric lamps. The power generated by the reactor could have been increased except that the reactor was located in the city. Neutrons leaking out would, at high power, have been dangerous to passers-by.

How power produced by the reactors at Hanford has been wasted

Success in this first crucial experiment led to the building of a larger experimental reactor at Oak Ridge, and to the design of the three great production reactors at Hanford. The production reactors were located in isolated country, to insure safety in case of accidents. They were also placed near the immense supply of pure water that flows in the Columbia River, which can be used for cooling. The atomic power generated in the manufacture of plutonium is immense. A reactor that makes one gram of plutonium per day must operate at a power level of a million kilowatts. Each second it liberates enough energy to bring two and one-half tons of ice-cold water to the boiling point. At Hanford, all this power is thrown away in heating the waters of the river, since the main purpose is to make plutonium. Nuclear reactors of the future will enable the atomic power to be used for the generation of electricity, or in some other useful way.

Tremendous amounts of shielding are needed around such reactors, because of the neutrons that leak out, and the dangerous rays that are emitted by the radioactive fission products. The large-scale chemical operations that are necessary to separate the plutonium produced in the reactor from the uranium must be conducted by remote control. This is because

of the intense radiation of the fission products that are present.

The Hanford plant was begun in June 1943, and was in full operation in the summer of 1945. Plutonium from this plant was used in the second atomic bomb of the war — the one dropped on Nagasaki. The plant continued to run after the war. The plutonium it produced was carefully stored away in neutron-tight containers containing masses smaller than critical. This plutonium may be used in the future for either peace or war.

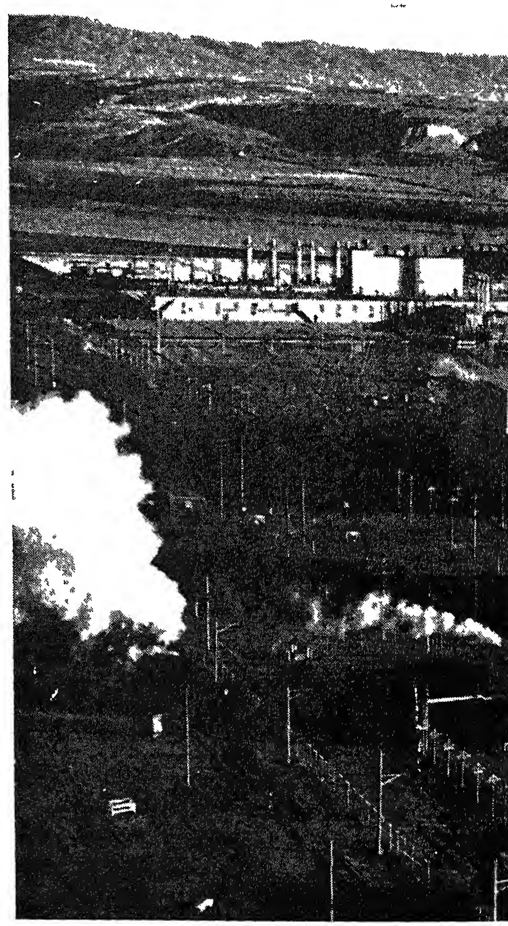
Uranium 235 is the only naturally occurring isotope that is suitable for maintaining a fission chain reaction. As we have seen, however, we can produce plutonium, another nuclear fuel, by burning U^{235} in a nuclear reactor. This Pu^{239} is obtained from the relatively "fireproof" U^{238}. This increases greatly the world's reserves of atomic fuel, for U^{238} is about 140 times as plentiful as U^{235}. Atomic fuel reserves can be increased still further by using the element thorium. Thorium can be processed in a nuclear reactor in the same way that U^{238} is handled. This processing results in the creation of uranium 233, which has a half life of 160,000 years and emits alpha particles in its decay. It is an atomic fuel with the same general properties as U^{235} or plutonium 239. It can be made to fission by the capture of even the slowest neutron.

How thorium can be used to keep an alchemical "fire" going

A nuclear reactor can be built in which the original "fire" is kindled and for a time maintained by U^{235}. It can then be kept going by the burning of U^{233} prepared from thorium bombarded by neutrons in the reactor.

Uranium and thorium are the only two elements of practical importance in the production of nuclear power by nuclear fission. They are relatively unfamiliar elements, but not at all uncommon. There is more of either in the earth's crust than there is of gold. Estimates put the uranium content of the earth's crust as some six parts in a million, and its thorium content at about twice that. This means that an average shovelful of dirt contains, in terms of atomic power, about the same energy that it would have, in old-fashioned chemical terms, if it were pure coal.

The atomic power developed during the war and immediately afterward depended on uranium that had been extracted from the very richest ores. So far as we know, such rich ore is strictly limited in amount. Large-scale development of atomic energy, then, must depend on the concentration of uranium and thorium from ores that do not contain high percentages of these elements. Gold has been mined commercially

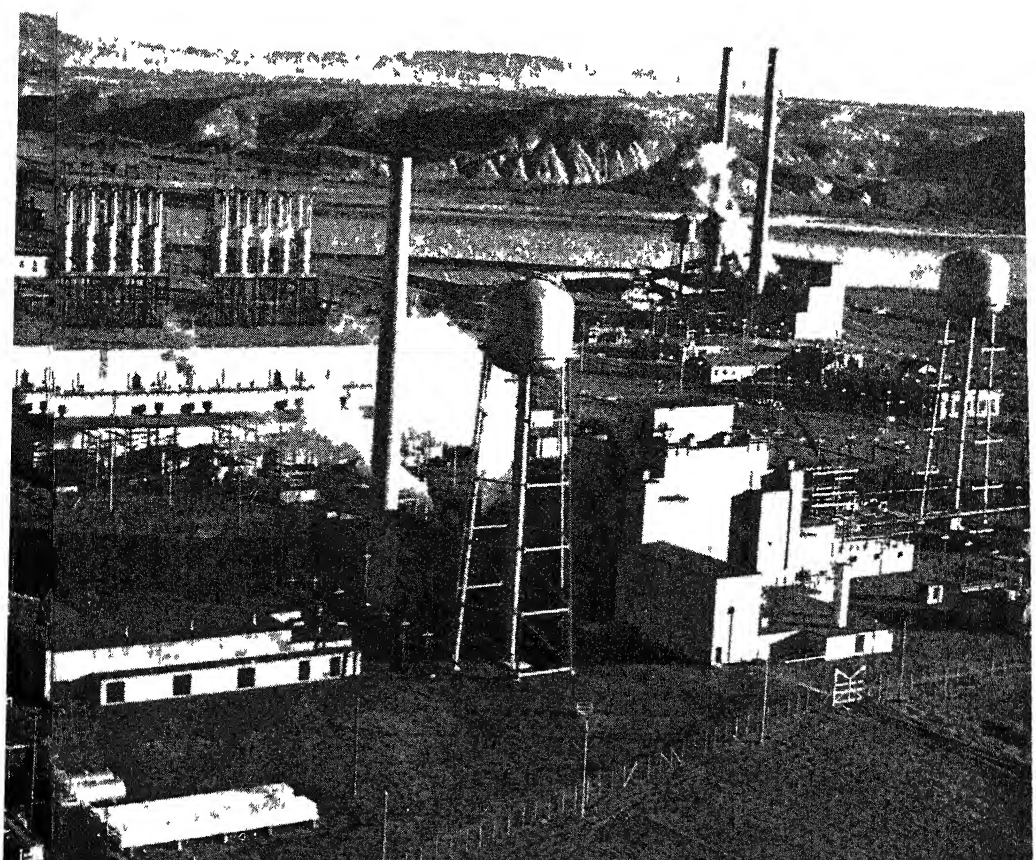


The sprawling Hanford Engineer Works, at Pasco, Washington, where plutonium 239 was produced for the atomic bomb that was dropped on

from deposits in which it is present in less than one part in a million. It may be that uranium will be commercially purified from ores not very much richer.

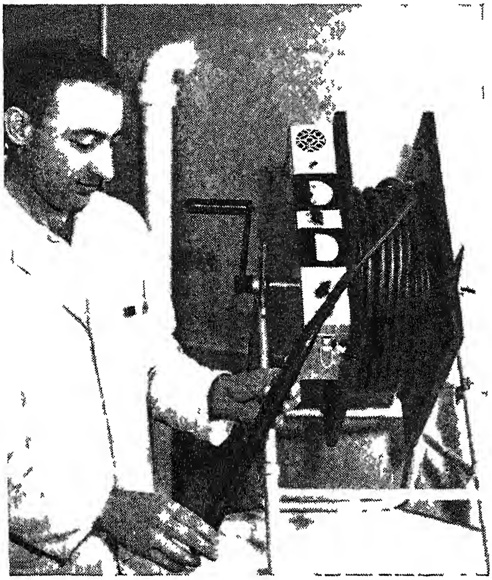
Let us turn for a moment from the small affairs of men to the stars. All the energy needed to sustain life and to power the machines of civilization has its origin in our star, the sun. Here on earth we receive from the sun about 5,000,000 horsepower per square mile. Considering the fact that the earth is so small and so far away from the sun, the total amount of energy radiated by the sun must be prodigious. The sun's total radiation energy, including the part that is intercepted by the earth, is about 50,000 billion billion horsepower. As a matter of fact, the earth intercepts only about 1/2,000,000,000 of the sun's radiation. Evidence from fossils found in rocks indicates that the sun has been sending out energy at about the same intensity for a long time. Both astronomy and geology would seem to show that the sun has been running at roughly its present rate for some 2,000,000,000 years.

But where does the energy of the sun come from? During the 2,000,000,000 years that the sun has been shining, it has sent out more than a million times the en-



Science Service, Inc.

Nagasaki. The plant was built in an isolated area so as to avoid catastrophic casualties and property damage in case of accident; it was located on the Columbia River so that the waters of that stream might be used for cooling. Hanford is a production center for America's nuclear-energy program.



Capital Press Service

The Geiger-Mueller counter shown above has been combined with a probe so as to detect the presence of uranium deposits in low-lying strata. A hole up to a thousand feet in depth is made with a diamond drill; then the probe is lowered into the hole. The counter will reveal the existence of the radioactive metal uranium if there is any in the stratum that has just been tapped.

ergy it could have generated if it had been made of coal and had been actually burning. Chemical burning — combustion — can not be the source of the sun's energy.

The German scientist Helmholtz suggested that the energy of the sun came from the sun's contracting and shrinking during the billions of years of its existence. He supposed that the sun was decreasing in diameter by one-third of one part in a million each century. This small amount of contraction would not have been noticed in any practical way, even over the entire span of recorded human history. This was an ingenious theory. Unfortunately, however, the amount of energy liberated by contraction of the sun could not have supported its radiation for any more than 2,000,000 years — a thousand times less than the actual age of the sun.

Only with the discovery of atomic transmutation, and the immense quantities of energy that could be released in this way, was an answer found to the riddle of solar energy. It is not atomic fission, however, that supplies the energy of the sun, but rather the nuclear transmutations involving the lightest of the chemical elements. These light elements are abundant on the sun.

What we know about the interior of stars like the sun must be deduced from our observations of surface conditions and our knowledge of the laws that govern the behavior of matter. The temperature at the center of the sun is probably about 20,000,000 degrees Centigrade. The pressure there is about equal to 150,000,000,000 atmospheres, or 150,000,000,000 times the pressure of our own atmosphere on the earth. Whenever the temperatures are as high as this, the atoms of matter are moving with such tremendous heat-energy that nuclear disintegrations will occasionally be produced simply by the collision of two atoms. Such an event takes place only once in a very large number of collisions, because the energy of the atoms is not high enough to produce frequent nuclear reactions. However, an unimaginably large number of collisions takes place each second between atoms in the interior of the sun. Even though the nuclear reactions are far less numerous than the collisions, their total number is still awe-inspiring.

The six-step reaction that accounts for the sun's energy

The reaction responsible for generating the sun's energy is a very interesting one. It is a six-step reaction in which four atoms of hydrogen are turned into an atom of helium with the help of an atom of carbon. The atom of carbon is necessary to the reaction, but this atom emerges unchanged at the end of the process. The energy set free in each cycle of this light-element reaction is about one-fifth of the energy liberated in a single fission reaction. However, the energy liberated per gram of substance reacting is more than ten times as great in the hydrogen-helium reaction as it is in nuclear fission.

The hydrogen-helium reaction, with carbon also taking part, is thought to be responsible for generating energy in most of the stars. In some stars, however, other

reactions involving the light elements are thought to be more important than the hydrogen-helium cycle. The interiors of such stars, though immensely hot, are too cold to permit the "burning" of hydrogen into helium.

We can make several predictions about the future possibilities opened up by man's liberation of energy from the atomic nucleus. The atomic bombs that were dropped over Hiroshima and Nagasaki are now old-fashioned models, for the United States Government has since produced several types of atomic bombs of much greater power and deadliness.

The principle on which the uranium or plutonium bomb works is that of nuclear fission, as we have seen. The nucleus of a suitable type of atom is bombarded with neutrons, the nucleus splits or fissions and tremendous energy is released.

The hydrogen bomb will be based on the fusion of atomic nuclei

Greater and more deadly is the hydrogen bomb, a weapon of war to end all wars, now being developed by nuclear scientists in the United States and possibly elsewhere. As far back as 1945 it was predicted that the energy of the atomic bomb could be increased a thousand times by using nuclear reactions involving light elements, of which hydrogen is one. The principle on which the hydrogen bomb will work, if it is ever successfully developed, is not that of fission, but of fusion — of merging together the nuclei of two atoms, with an unbelievable amount of energy left over.

In the hydrogen bomb (sometimes known as the tritium bomb), ordinary hydrogen, such as that which combines with oxygen to form water, could not be used. Hydrogen has three different forms, with mass numbers 1 (ordinary hydrogen), 2 and 3. Hydrogen of mass number 2 is known as deuterium. Its nucleus contains one proton and one neutron. Hydrogen of mass number 3 (the rarest kind) is known as tritium, with a nucleus containing one proton and two neutrons. Ordinary hydrogen can be converted by changes in its nucleus to the other types. In a successful hydrogen bomb, nuclear physicists must find some way to make the atomic nuclei of tritium and deuterium, or of two atoms of tritium, combine or fuse together in the presence of very high temperatures.

The plutonium bomb could be used as a trigger for the hydrogen bomb

It is known that the temperature in the plutonium bomb as it explodes is probably in the neighborhood of about 20,000,000 degrees Centigrade, which is, as we have seen, about the temperature at the center of the sun. No such temperatures as this are possible on the earth, of course, because such heat would melt everything around it The plutonium bomb, however, creating such heat for a split second, can be used as a trigger for the hydrogen bomb, to set off the reaction that will cause the fusion of the nuclei.

When a nucleus of tritium and one of deuterium come together in fusion under such temperatures this is what happens An isotope of helium will be formed, a neutron will be emitted and energy about a thousand times more destructive than that produced by the atom bomb will be liberated. When the nucleus of an atom of tritium is fused with another tritium atomic nucleus, an isotope of helium will be formed, two neutrons will be emitted and energy, somewhat less than that produced by the tritium-deuterium reaction, will be liberated. There are many problems for the nuclear physicist to solve, however, before the hydrogen bomb becomes a reality.

The more cheering possibility of using atomic energy as a source for conventional purposes of power, propulsion and commercial manufacture is an obvious one. Work is already under way on the development of a power reactor that could provide heat energy for the operation of dynamos; these dynamos, as you know, generate electrical power. Designers of such power reactors must solve the problem of corrosion and the harmful effects of radioactivity in a reactor operating at a high temperature. The solution of these problems seems to be at hand.

Atomic-power reactors will undoubtedly

be used for the propulsion of ocean vessels and of aircraft. With nuclear-power installations, the cruising range of a ship or an airplane would be unlimited. Plans are now under way to develop such power for submarines. The possibilities of powering aircraft by atomic energy are more remote.

Operation of a nuclear reactor produces enormous quantities of radioactive isotopes of the common elements. Some of these radioactive isotopes are fission products — the fragments of the divided uranium atom. Others can be prepared by introducing stable elements into the reactor. Certain radioactive isotopes can be used for the treatment of disease. For example, when the element iodine is introduced into the body, it is taken up almost entirely by the thyroid gland. When radioactive iodine is given to a patient suffering from a disease of the thyroid, the effects of the radiation emitted by the iodine are therefore confined almost altogether to the diseased thyroid gland. Similar specific effects involving other organs of the body may be shown by other elements, or by special compounds.

Radioactive substances are also of great value in experimental medicine, biology, chemistry, physics and engineering, because they permit the use of what is called the tracer technique. Very sensitive methods are available for detecting the presence and measuring the quantity of radioactive materials. With such a device as the Geiger counter we can actually register the disintegration of single radioactive atoms. Therefore, if we wish to follow the history of the element phosphorus after an animal takes it in with its food, we need only prepare the phosphorus-containing food with a very tiny amount of radioactive phosphorus mixed with the ordinary phosphorus. Measurement of the radioactivity of the food after it has passed through the animal's body will tell us how much phosphorus the body retains. The radioactivity of any bodily organ will tell us how much phosphorus that organ absorbed. Tracer techniques of various kinds can be used in a great many other scientific and engineering fields.

A steadily increasing number of physicists are devoting themselves to nucleonics, the science of nuclear phenomena. We can not guess in what directions the advances in our alchemical knowledge will lead our science and technology. But the discovery of alchemical "fire" may well rank with the discovery of chemical fire in its effect upon our civilization.

Acme

This closeup shows particles of sand seared by the atomic bomb that was set off near Alamogordo, New Mexico, on July 16, 1945. The sand around the tower on which the bomb was suspended was transformed into jade-green glass-like particles. Two months after the blast these particles still contained minute amounts of radioactivity. The area that was affected covered 2,400 feet in diameter.

LAWS OF RACIAL CHANGE

Two Great Men's Competitive Discoveries of How the Fittest are Selected to Survive

A SOMETHING MORE THAT DARWIN MISSED

"EVOLUTION was in the air"; the theory that living species were descended from other and simpler forms had taken hold but the obstinate *how* remained, and there were no answers which satisfied even those, such as Huxley, who most anxiously desired them. Scarcely anyone noticed Herbert Spencer's work, and his arguments in many a conversation did not convince Huxley. For lack of some convincing assertion of a *method* of organic evolution, the battle between "special creationists" and "evolutionists" seemed something like a stalemate. Into this half-frozen sea of thought Charles Darwin launched, in 1859, the ice-breaker called "The Origin of Species". Our business here and now is to learn what Darwin taught, to weigh its significance for his own time and above all, to analyze very carefully, in the light of our knowledge today, the exact worth and precise limits of the central doctrine which we associate with his name.

Already in 1839, at the age of thirty, Darwin had abandoned the view that species are immutable, and had opened and filled his first notebook of facts that might explain how they change. For nearly twenty years he worked steadily at the subject, accumulating evidence that more and more clearly pointed to the truth of a theory which early suggested itself to him. Then, in 1858, Dr. Alfred Russel Wallace sent him, from the other side of the world, a brief account of the same theory in very similar language, asking his opinion thereon, and his help, if he saw fit, for its publication. Darwin naturally concluded that he must at once publish Wallace's paper, and lose the honor of priority — though the theory had been framed by himself many years before, and he was only waiting to announce it in order to add to his already immense stores of evidence.

Illustrious friends were consulted, and the plan was followed, with the consent of both authors, of reading a joint paper before the Linnæan Society.

"Natural selection" was the term which Darwin introduced to express the theory in question. It is not a good term, for it is not self-explanatory, and it seems to point to some conscious agency that selects. It has a still more serious defect, which we shall later consider. We may ask how Darwin came to use a term that has such drawbacks. The explanation is that he wished to show the parallel existing between natural selection and artificial selection.

A patient student and observer of animals and plants under domestication, he saw that species of living things are capable of profound modifications by the process of deliberately selecting certain kinds from which to breed. And it occurred to him that what conscious agency accomplishes in such cases other agencies may be conceived to accomplish in the case of animals and plants that live in natural conditions; so that, just as the human breeder selects the types he desires and breeds from them, and develops new forms, so nature, the breeder of all living things, including men, somehow selects certain types and so develops new species. Natural selection is thus an argument by analogy from artificial selection.

Theory of a mathematical philosopher that we are heading towards starvation

But how, we may ask, did this idea occur to Darwin? In his famous "Essay on Population," published in 1798, the Rev. Thomas Malthus had discussed the consequences of the growth of human population faster than the food-supply to sustain it. Malthus argued that population tends to increase in geometrical progression, while food-supply can only increase in arithmetical progression. Plainly someone must starve. From these considerations, he argued for late marriages, in order that the growth of population might be slower and that the "struggle for existence" might be less terrible for the poor.

Inferences drawn simultaneously by two thinkers half the world apart

Darwin read this essay in the 'forties and Wallace in the late 'fifties. To both the same idea occurred. "Someone must starve," who should the someone be? If two men run to one loaf of bread, who will get it? Or if the two fight, who will get it? We see the answer now. A factor of selection has been discovered which parallels the work of the human breeder. There must be what Spencer called the "survival of the fittest"— which instantly explains the everywhere illustrated fact of fitness or adaptation between an environment and the species that inhabit it.

If food is to be run for, or if one must run in order to avoid being eaten by someone else, then fleetness is fitness; and fleetness survives, together with those kinds of bodies and limbs that make for fleetness. If, on the other hand, to be immobile and pretend to be dead or uneatable is to survive the attentions of the would-be eater, then those creatures who are cleverest at looking like pieces of stick, or dead leaves, or what not, will be the fittest, will survive, and will leave offspring like themselves among whom the same selection occurs, until we find the staggering adaptations, mimetic resemblances, etc., which naturalists have since studied for us.

First of the three conditions natural selection requires for its action

Clearly, then, natural selection is not an inevitable and constant factor in the course of animal and vegetable life; nor is it purposeful, deliberate, intentional, with an ideal to aim at, like the artificial selection by the human breeder to which Darwin likened it. Yet it acts as if it had an ideal; and that ideal is adaptation. Just so does a sieve act, quite mechanically, as if it had an ideal, provided that the necessary conditions for its working are present. It is now our business to note very carefully the three cardinal and indispensable conditions which natural selection requires for its action.

Malthus had seen the first. It is over-production of new lives, so that not all can survive. The essential meaning of "over" in this definition is in relation to available food. Natural selection has various forms, but the typical and general form, far more important than all the others put together, is that of a competitive struggle for an inadequate food supply. When we say *over*-production, we mean that the food-supply is inadequate. In this principal form of natural selection — not in the popular misinterpretations of the term, but in the strict scientific sense — the process ceases directly the production of new life falls to the level of the available food, or directly the food-supply is increased so as to be adequate for all comers. The great, representative instance of natural selection, as understood by Darwin and Dr. Wallace, is the struggle for food among the immature members, in especial, of living races. The death-rate among them measures the number of those who have failed to obtain the food, whatever it be, and from whatever cause.

Two vastly important observations require to be made at this point, before we leave the bare statement of the primary condition for the working of natural selection. They both refer to man, who is the double exception to the normal course of nature in this respect.

First, it is not true, as Malthus supposed, that food-supply can only increase by arithmetical progression. On the contrary, it is often itself a matter of the growth of living species — say, of rice or wheat, sheep or fowls. Under suitable conditions, such living species exhibit the tendency, already proclaimed by Malthus for the case of man, to multiply in geometrical progression. Now, man is the master of other species. He can set them going in new conditions, when and as he pleases, and so create his food-supply

In the sense in which the word "natural" is used in Darwin's phrase to mean mechanical and automatic, man is supernatural, and may at any time, if he chooses, totally reverse the state of things as to growth of population and food-supply, respectively, which Malthus predicated.

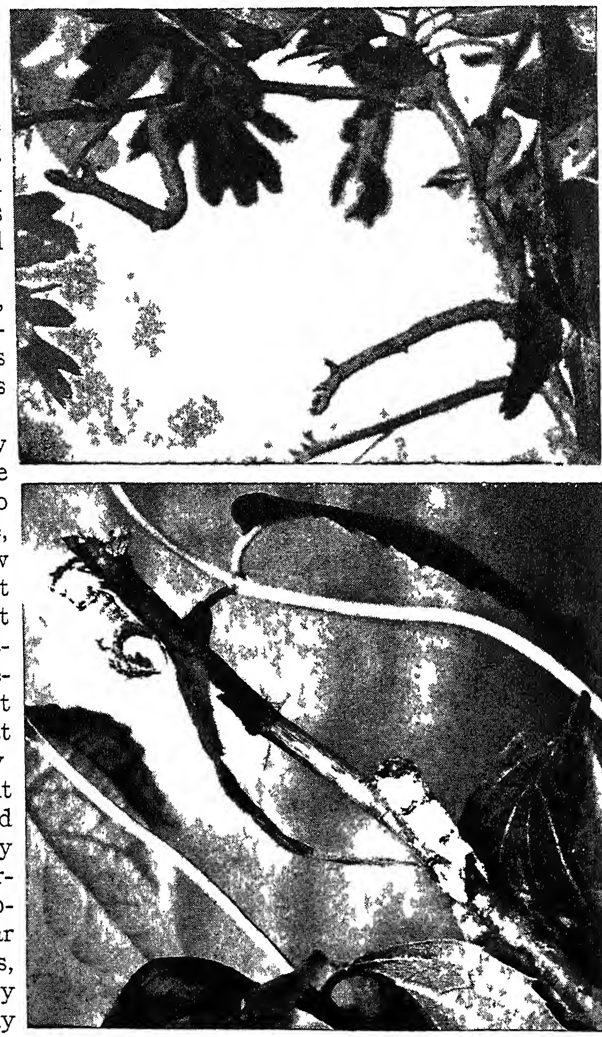
It has often been wondered why Malthus, having discovered over-production and the "struggle for existence," should have stopped there, when apparently but one obvious step was required for him to

HOW THE CATERPILLARS OF THE V-MOTH FEIGN DEATH AT THE APPROACH OF DANGER

Secondly, he may and does control his own birth-rate, as no other living creature does. It follows that the first condition for natural selection is not satisfied in many illustrations furnished by man. It was quite necessary, in the interests of just statement, to interpolate these two notes on the Malthusian proposition; they teach us that man may be an exception to the very state of things which Malthus asserted about man especially, and they prepare us to understand that, perhaps nine times out of ten, when people talk about natural selection in the case of man, they are using words without knowledge.

see and assert the consequences of the struggle — that the fittest must survive. But the reason why Malthus stopped short is evident. He was not a naturalist, but a clergyman He was not familiar, as were Darwin and Dr. Wallace, when their time came, with the two great facts called heredity and variation. And those are the two conditions which natural selection requires, as we shall see. Spencer, in his turn, came to the problem of evolution. But he was not a naturalist either. His training was in engineering. The facts of heredity and variation were not known to him at first-hand, any more than to his clerical predecessor.

But both Darwin and Dr Wallace were, above all else, naturalists From their very earliest years they had the passion for collecting which is characteristic of the born naturalist Now, two tremendous facts steadily impress themselves upon the naturalist They are first, that living things run in species or kinds, or types, in virtue of the fact that offspring are like parents Beetles beget beetles and not acorns, cows beget cows, and not cabbages This is, of course, the fact of heredity, which seems fairly obvious when thus stated but which many sapient people are still found to deny Of course, they do know that oaks beget acorns, and not apples or antelopes, but somehow they do not quite grasp that this is heredity But of course it is heredity, and on closer inquiry we find that certain kinds of apples beget similar kinds of apples, so that heredity applies not only between species, but within species as well



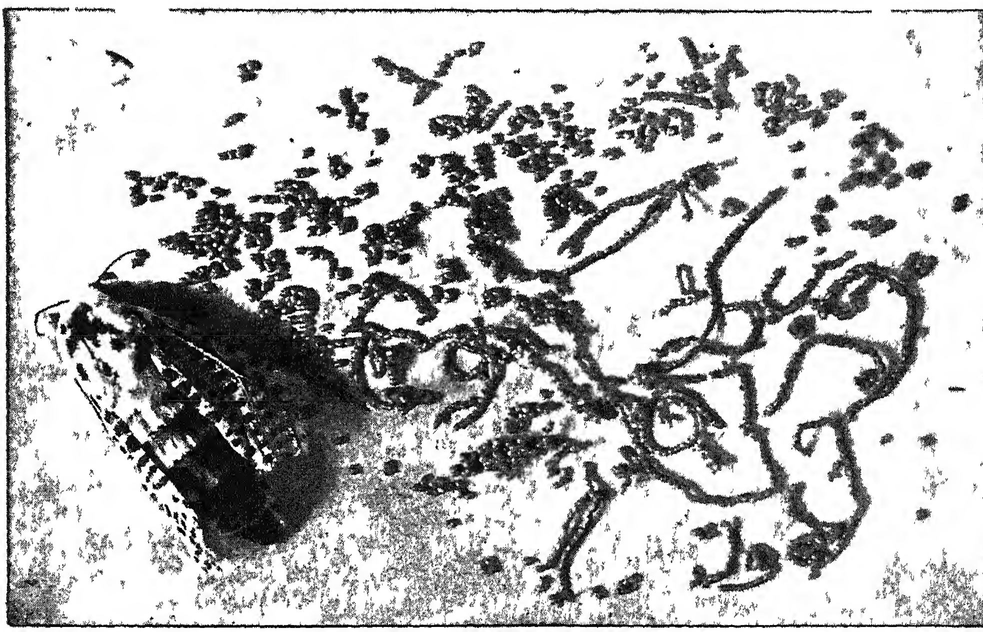
CATERPILLARS AND MOTHS THAT MIMIC STICKS
The upper picture shows two stick like caterpillars of the Purple Thorn moth The lower picture shows two Buff Tip moths at rest, when they resemble broken bits of stick

However, though "like begets like", it never begets *exactly* like There are little differences, and sometimes great differences, as well as great hereditary resemblances, between parents and offspring. This we call variation, and for the present we may contrast it with heredity as a kind of opposite, though we shall see later that this idea of heredity and variation as opposites is only a rough-and-ready one, which deeper study qualifies Meanwhile, we understand that the first-hand observer, the born naturalist, like Darwin or Dr Wallace, would be familiar with the fact of variation, even from the age of four or five when gloating over shells or any other products of life You cannot put two shells of the same kind together in a tray without seeing, if you are really looking at them, that they are very like and yet that they are not exactly like

Here, then, is the answer to the frequent discussions as to Malthus and Spencer missing what they came so near These first-hand students had a vital grasp of the three great facts, over-production, heredity and variation, which had only to be thought about for the theory of natural selection to form itself The theory, as expressed in the full title of Darwin's great work, "The Origin of Species by Means of Natural Selection or the Preservation of Favored Races in the Struggle for Life", asserts that new species result from variation in offspring advantageous in life's battles and transmissible to posterity.

First, there must be the struggle No struggle, no selection Given, then, the struggle, which depends upon over-production, the factor we have called variation asserts that some of the strugglers will be natively endowed with advantages over others They will be a little fleeter, or keener-eyed, or sharper-toothed, or stronger-stemmed or more profusely leaved, than their fellows Or, in the sand of the desert under the glare of the sun, their coats will happen to be the best match for their surroundings and therefore the least visible an advantage either to the stalker or the stalked

But so far we have only invoked two of the three factors which we stated to be essential to the working of natural selection namely over-production involving struggle and variation among the strugglers But we said that heredity was essential also And so it is for the offspring of the fittest who have survived inherit their parents fitness Thus the next generation will start from a new average so to speak, and while some of its members will be more fit than others (owing to variation again) the whole of the next generation will be fitter or better adapted, as a whole because by our



AN EXAMPLE OF OVER PRODUCTION — A LEOPARD MOTH WITH A BATCH OF ABOUT 1000 EGGS

Instances are infinite in number But in every case it must be that, given a fair field and no favor, and given that only some can survive, the survivors will be the fittest Foolish critics have declared that, when Darwin's theory is properly examined, it means nothing more than the survival of the survivors It must require some hardihood to utter such puerilities The survival of the survivors is a necessity of thought Darwin's theory tells us who the survivors will be they will be those best able to survive, those best adapted to the conditions in which they are found — in short, "the fittest".

theory, it inherits the fitness characteristic of its parents, who were the survivors from the generation before

This is the simple theory with which Darwin shook the world when he published his masterpiece in 1859 Half a century later, the event was commemorated by suitable ceremonies at Cambridge, and by the publication of a handsome volume, in which leading biologists discussed the relation of the Darwinian theory to the more advanced knowledge of our time No careful student of that volume could fail to perceive how far we have indeed moved on from the

position which Darwin won for us, and how different — in the most essential matter of all — is our estimate of the theory of natural selection from that which was put upon it, never by Darwin himself, nor by Herbert Spencer, but by all Darwin's followers, from Huxley, Haeckel and Weismann down.

THE ICHNEUMON FLY THAT HAS DEVELOPED A VERY LONG OVIPOSITOR

In the struggle for existence this insect has become especially adapted to lay its eggs in the bodies of caterpillars lying beneath the bark of a tree, its young being born in and feeding on the bodies of their hosts.

We have already seen how Spencer aided the Darwinian theory by inventing the term "the survival of the fittest," which Darwin gladly adopted, and which is, perhaps, the most famous phrase invented in the nineteenth century. In his masterly and constructive criticism of Darwin's theory, notably against such critics as the late Lord Salisbury, Spencer pointed out that, given the three necessary conditions which we have described, the theory of natural selection answers to his famous description of the ultimate test of truth. The last test of truth for finite man is that the opposite of the proposition asserted shall be inconceivable.

If the laws of our reason make it impossible for us to conceive the opposite of a statement, that is the furthest we can go in demonstrating its truth. We can readily conceive, for instance, the opposite, or negative, of any part of the law of gravitation; that is not one of the most certain truths at all, true though it may be. But we cannot really conceive the opposite of the law that "nothing is made from nothing," the law of the conservation of energy, and we cannot conceive the opposite of the law which asserts that, in a life-and-death race for food, the runner who is fittest to get there first *will* get there first. Thus the law of the survival of the fittest, like the law of the conservation of energy, is one of those which are as certainly true as anything can be, because we cannot conceive their opposites.

And no one who has a right to an opinion now questions the truth of the law of natural selection, or the survival of the fittest. Everyone is bound to see that, wherever the conditions obtain, the law must work. Further, we must all agree that this law explains adaptation or, rather, as is just beginning to be seen, explains the absence of non-adapted species. We see that natural selection is the stern judge before whom all aspirants to existence have to pass. If they are challenged by other aspirants better adapted to the conditions of the environment, then, inevitably, the best adapted must win. This is a necessary process, wherever the conditions obtain, and they almost everywhere and almost always do obtain.

Thus there is a salutary process almost always at work, which is ever judging and shaping species. All the forms of life we know are thus the survivors, in a competition which goes on from generation to generation, and which is incessantly weeding out those who were and are less

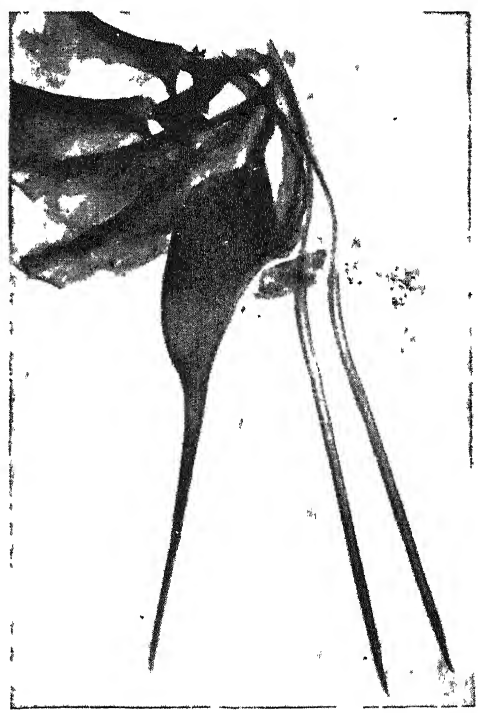
qualified to win. This is nature's competitive examination for life, with the privilege of reproduction as a prize for the successful; and its consequence is always to increase the adaptation, fitness, viability, of living species, while little record or none remains of the innumerable hosts who have been worsted sooner or later and who, seeking to be feeders, have been condemned to the humbler function of food

"Sooner or later," we have said; and nothing in this theory is of more importance than to realize that this is an examination which is always going on — except for the abnormal case of man, as may sometimes appear. Nature gives no final verdict. Past success, high qualifications at such and such a time, and a brilliant record since — these are absolutely nothing to her. The question for every living species and every individual thereof is · Can you live and beget *now?* It is of no use for the species to say that it has existed since the Silurian age unchanged, or for any portion of it to say that it beat another portion at Waterloo. Natural selection looks not backwards, but forwards, and judges the present accordingly.

A point of relatively small importance from the standpoint of organic evolution in general is worthy of note here, before we pass on to ask the searching question that remains It is that natural selection, as asserted by Darwin, is mainly between members of the same species, and only subordinately between the members of one species and those of another. It is intra-specific rather than inter-specific.

The importance of this distinction lies in what we seek, by natural selection, to explain. If we wish to explain the balance between species, their mutual relations, and their adaptation to one another, then it is the struggle between species and species that we must invoke. But it is adaptation in general, the fitness of each species for its surroundings as a whole, that is the chief problem of organic evolution, and the only kind of struggle and selection capable of explaining that is the selection within a species, ever excluding the less adapted, selecting the better adapted, and so, at last, shaping the type of the species into the marvelously adapted forms that we see on every hand, whether in the animal or the vegetable world.

But, on the other hand, we are not to suppose that species are adapted to suit each other, for the sake of each other. Each species for itself is the rule. Individuals may and do exhibit characters which do not serve themselves, but those of other individuals of the same species



THE STING OF THE WORKER-BEE
In this photograph the sting of the bee is shown to the right of its sheath, magnified many times.

That we see repeatedly, from the sting of the worker-bee, which exists for the hive, and the employment of which involves her own death, up to the breast of the mammalian mother, which serves herself not at all, but the race indispensably.

On the other hand, we may search high and low, but we never find any character of any species existing *in order to* serve any other species. More than fifty years ago Darwin declared that he could find no such instance, and none has been found since.

In our statement of the theory of Darwin and Dr. Wallace, we must especially observe that it leaves on one side the possibility of adaption through the inheritance of characters acquired by parents. Lamarck said that the giraffe stretches its neck by use — or, rather, the ancestors of the giraffe did so — and that the successive offspring acquired in this way their adaptation to their particular mode of feeding. The theory of Darwin says that giraffes are born, some liable to be taller, and some shorter. Where food is scarce, and tallness favors feeding because it makes the leaves of trees accessible, tallness will be naturally selected in successive generations, and so the giraffe we know will be produced. The two explanations of evolution are fundamentally different, and must not be confused. We need only to note further that Darwin accepted the view of Lamarck as contributory to the origin of species, where it is applicable; but modern Darwinians totally deny the possibility of the "inheritance of acquired characters," and call themselves neo-Darwinians, or new Darwinians, more Darwinian than Darwin, "*plus royalistes que le roi*".

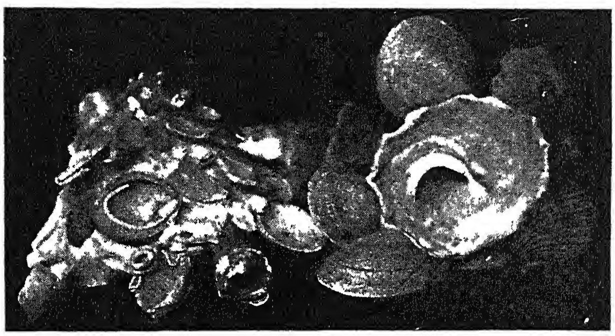
Finally, we must note the essential feature of this theory, which is the accidental character of the variations that make evolution possible. The variations are regarded as absolutely fortuitous, to use the accepted term. Some are in one direction, some in another; the only law which governs their production and occurrence is the law of chance. They are thus like the shots round the bull's-eye of a target, distributed all round it, denser nearer it, and ever fewer and fewer the further they depart from the average or type of the species. Natural selection then chooses among these random variations, according to their relative fitness.

This is the crucial moment of our whole inquiry. Darwin himself never made the mistake of consciously supposing that he had accounted for the production of *origin* of the variations which natural selection selects. But in naming his book "The *Origin* of Species," and in the use of the term "natural selection," he inevitably made possible, if not for himself, at any rate for others, a conception of his own theory which will not hold water. If species arise in certain variations, then the problem of the origin of species is the problem of the origin of those variations, those new forms of life, which natural selection then selects. The theory of natural selection therefore explains the fixation of species, the non-persistence of the non-adapted or the misfits, and the survival of the well adapted or fit. But it tells us nothing as to the "origin of the fittest". In short, while it contributes to every problem in biology, and solves many, the one problem, above all, which it does not illuminate and to which it makes no contribution whatever is the problem of the *origin* of species.

The misunderstanding, which is gigantic, and which endured even among the highest authorities for something like four decades, was due to what we have already hinted at as the most serious objection to the phrase "natural selection". The phrase gives a positive color to what is essentially a negative process. The proper name for the process called natural selection is "natural rejection". Undoubtedly, to choose is simultaneously to refuse, to select one of two things is to reject the second. But the process, as it actually occurs in nature, is admittedly a negative one; it consists in the persistent extinction of the less adapted, a negative process which involves the positive corollary that the more adapted are not extinguished.

The distinction between the two terms is not merely verbal, nor is there any better instance of Bacon's argument about the deceptive influence of words upon the understanding. If natural selection had always been thought of as what it is, namely, natural rejection, no one would ever have supposed that the phrase somehow explained the origin of species. The rejection of anything does not produce anything else. *Nor does natural rejection produce the forms which it spares.* The problem of the origin of species remains untouched; and though Darwin's work contributed to everything else, it contributed nothing to that.

It is no easy matter to persuade those who have not been through all this work for themselves that Darwin's theory retains an indispensable value, and that his work and his fame can never be dimmed. Yet such are the facts. Natural selection and the other forms of selection are unquestionable realities. Between them they have the most potent influence in molding and controlling all the forms of life. everywhere and always; and never were the study and appreciation of them more necessary than at the present time when students are attempting to erect, largely upon the foundation of biology, a new science, which they call eugenics. Both on theoretical grounds, and for the momentous character of their practical applications, the forms of selection must be studied more closely than ever — not least that which Darwin later described and to which he gave the name of "sexual selection," for the consequences of this process may be stupendous. But the first step towards any possibility of really appreciating the significance of the idea of selection in biology assuredly is to perceive that selection selects — or, rather, rejects — but does not create. The problem of the "creation," "origin," "evolution," of what selection selects is still our problem today.

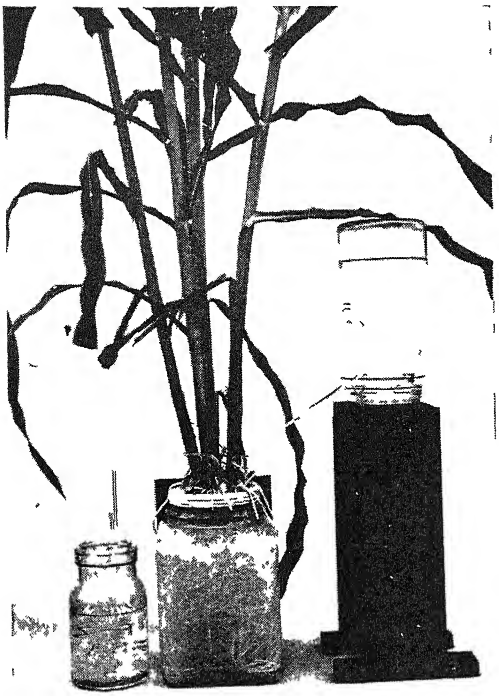


PROTECTIVE MIMICRY ON THE SEA BOTTOM

These sea-snails from the West Indies cement lime and stones to their shells.

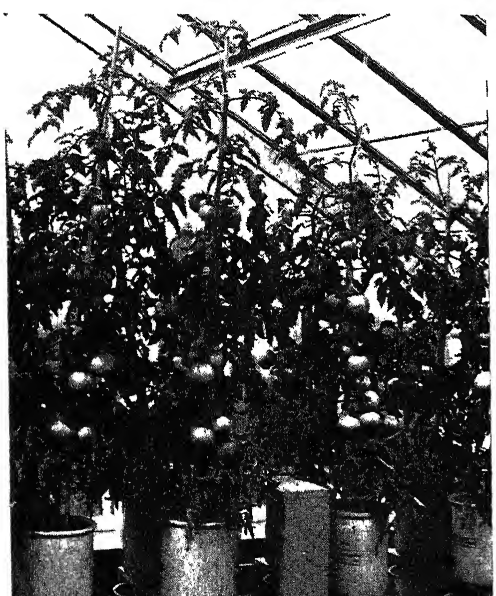
Fortunately this perplexing problem is clearer to us today. We find now that genetics is giving us a more adequate picture of the mechanism of evolution. The actual origin of species seems to lie in the occurrence of spontaneous changes (mutations) within the germ plasm of a species. If a change or mutation is favorable to an individual we know that natural selection will favor it and that in a small population it has an excellent chance of spreading to the entire group. It is in this way that differences are built up between species. They arise first from within the species itself, and, if favorable to the species, are maintained by natural selection. Mutations have been carefully studied by geneticists, they can be artificially caused by x-rays and certain chemicals. We know that in nature they occur rather infrequently, but by increasing the mutation rate with x-rays, we are now convinced that they form the reservoir of variations from which the various species have been created.

The magnificent analysis of Professor Henri Bergson, in the first chapter of his "Creative Evolution," has furnished from the side of logic and philosophy an exact complement to the work on variation which was begun by Mendel, and is now remaking our theories of evolution. Professor Bergson has seen a new argument after all these decades which strikes at the very root of the mechanical theory. He points to the eye in vertebrate animals, with its marvelously delicate, complex, and exactly suitable parts. It is sufficiently difficult, he declares, to believe that this organ has been mechanically evolved by the accumulation of accidental variations which natural selection could choose from. But an eye of closely similar structure is found in some molluscs, animals of radically different structure and belonging to an utterly different branch of the tree of life. The theory of natural selection, in asking us to believe that the same long series of happy accidents has occurred independently along these two lines, strains belief to breaking-point. It begins to be evident that there is something called Life, which responds to the touch of light, and evolves the seeing eye; something, as Bergson says, "of the psychological order," immanent in all living things, low as well as high, which feels and strives and achieves, and which made the eye, as man made the microscope.



The continuous flow method of renewing the culture solution in the center jar by siphoning from the reservoir jar at the right. This plant shows excellent development of tops and roots.

Continuous flow method of supplying a tomato plant growing in sand with nutrients which drip from the reservoir of culture solution in the glass jar. Waste solution drains into the bottom pan.



These tomato plants, grown in sand culture, were fed with waste nutrient solutions. The culture solution which dripped from experimental plants was collected and used to grow these tomatoes.

Photos courtesy J. W. Shive and W. R. Robbins, N. J. Agricultural Experiment Station

A tobacco plant grown in sand in a 9-inch pot. By means of the continuous flow method large plants may be grown in relatively small pots.

PROPAGATION OF PLANTS

Artificial Reproduction by Cutting, Layering, Budding and Grafting, and the Problems of Hybridization

WHERE PLANT AND ANIMAL GROWTH DIFFER

WE have been considering to what an extraordinary extent it is possible for man to interfere in the normal life of plants and trees for purposes of his own in the direction of producing trees of various sizes and shapes, and fruits of special quality. We have referred to the methods by which these processes are carried out as the "surgery" of plants; and we have already pointed out that the plant surgeon actually goes so far as to create species of a type which he himself has mentally conceived. This he does by the process of hybridizing. But there are yet other possibilities of plant surgery to be considered.

It will be recognized, of course, that all these processes, directed to the production of special types of plants, depend really upon the phenomenon of reproduction in plants; and it may be well here to emphasize that this physiological function of reproduction, by means of which plants have the power of producing new individuals, occurs in two distinct ways in the vegetable kingdom.

We have, for example, reproduction by sexual methods in plants just as in animals, methods which are known as 'fertilization," and concerning which we shall have a good deal to say later. At the same time, reproduction in plants may be carried out by what is termed the "vegetative" method, and it is to this process that we are at present directing our attention

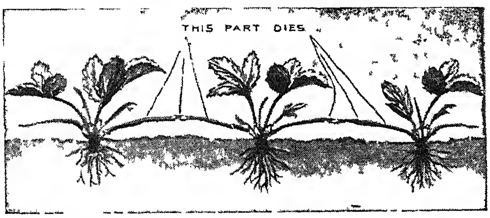
Vegetative reproduction in plants is a phenomenon which may be seen in quite a number of different phases, and it may occur either naturally or by artificial interference on the part of man.

An example of natural vegetative reproduction and multiplication is seen in the potato, in which the underground roots, which proceed from the parent plant, grow into thickened and swollen portions at their extremities — the potato or tuber. In ordinary agriculture this is dug up for food; but if it be left in the ground when the stem dies down, every tuber or potato in the following year will, by the process of vegetative reproduction, spring up as a new plant. This is quite a common process with plants having underground roots.

Another instance of this process of reproduction is that seen in the strawberry. A strawberry plant, left to itself, produces a number of "runners," which spread over the ground in various directions from the central plant and take root at intervals. From each node at which the runner takes root a growth of a new individual plant arises, and the separation occurs by gradual decay of the tissue of the runner. Many similar instances of vegetative reproduction are seen among bulbous plants.

It was doubtless originally from the observation of this natural process that the primitive gardener conceived the idea of imitating it artificially. If plants could give rise to new individuals by rooting little pieces of themselves in this way, why should not man take such portions of plants as he wished and make new individuals from these? True, it is a somewhat extraordinary thought that a small portion of a plant cut off from its parent stem and placed in the ground should have the power of producing a complete individual with all its parts, but it is, nevertheless, true.

This is one of the marvels of plant life as distinct from that of the life of higher animals. It is a fact that a piece of a root, a portion of a stem, or—still more wonderful—even a portion of a leaf of some plants, separated from the parent growth and put into an environment which offers suitable nutrition and protection, are ac-



VEGETATIVE REPRODUCTION — SELF-LAYERING STRAWBERRY RUNNERS

tually capable of producing roots for themselves and ultimately complete individual plants having all the characters of the parent plant from which they were taken. This primitive discovery, probably made when man carelessly stuck a stick into the ground and left it there, and which was afterwards found to have taken root, doubtless led very soon to the method of propagation of plants by means of cuttings. Observation of other plants would lead to artificial reproduction by means of layers as well as cuttings, and these in time to the more elaborate procedure of budding and grafting

VEGETATIVE REPRODUCTION BELOW THE SOIL

The lily-of-the-valley differs from the strawberry by developing its branches underground, as here shown.

In the process of vegetative reproduction from cuttings, any portion of the plant, be it leaf, branch or root, may be used. The greatest development of roots, however, always results when the end of the cutting nearest to the earth in the parent plant is the part that is planted.

As examples of plants which may be propagated from root cuttings we may mention pelargoniums, while an example of propagation from leaf cuttings is to be found in the well-known begonia. In the latter case it is only necessary to place the leaf, or a portion of it, on moist soil in a suitable temperature, and nature will do the rest. It is more common, however, to select young shoots for propagation by cuttings; and these are cut off just below a node, as it is at this point that the new roots appear. Many of our domestic plants are readily and easily propagated by this method, among the most notable, perhaps, being currants and gooseberries. The cutting is usually from eight to ten inches in length, and is taken from the parent plant at the end of a season's growth, when the leaves have fallen off. The buds on the cutting are rubbed off where it is to be inserted under the ground.

Vegetative reproduction by means of layers is done by fixing a portion of a young shoot into the earth by an artificial pin of some kind. The shoot is simply bent down and forced underground to such an extent that it is well covered. In due time the underground portion gives off roots; and when that has happened the bent portion above the level of the soil may be divided with a knife, thus severing any connection with the parent plant. Imperfect division of the portion bent underground is also practised to prevent the flow of sap back from the free portion of the shoot. This helps in the formation of new roots. Naturally, it is easier to start a new plant by means of layering than it is by cuttings, because in the layering process the connection between the old plant and the one that is to be produced can be maintained as long as necessary. As a matter of fact, this process is largely used when it is wanted to grow apple, pear and other fruit stocks quickly, these being used afterwards in the further process of grafting and budding.

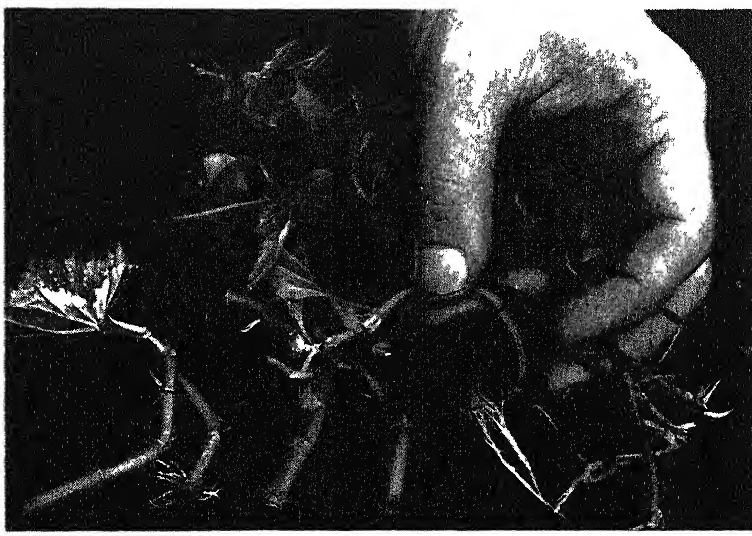
Budding and grafting may be regarded as being operations which demand the greatest skill and judgment, both in selection of the tissue to be used and in the technique of the procedure itself.

In budding, a bud is cut from one plant and inserted into a stem or stock (main stem, or trunk) of another. Grafting is accomplished by transferring a piece of a shoot, which bears several buds upon it, to an entirely new stem. The shoot itself is spoken of as the graft or scion. The roots of the plant that receive the bud or scion gather nutriment, such as water and its contained ingredients, which then circulate up the stem and into the tissues of the graft. Thus graft — or bud — and stem live one life and derive their nourishment from a common root, which, nevertheless, retains its own special peculiarities. Consequently, we may observe the extraordinary phenomenon of entirely different qualities of fruit growing from a single branch — one from the graft with its qualities, the other from the original stem with its qualities. Indeed, it is quite possible to have a number of different, but closely related, types of fruit grafted to a common stock.

Most of our readers have at one time or other observed two branches of a single tree, or two branches from separate trees, that have happened to grow in such directions as to cross at an angle and to come into contact with one another. When this occurs, in the course of time they frequently grow together and physically unite. Such a natural occurrence suggests that a great variety of similar operations might be artificially performed.

The various processes that effect the transfer of branches or buds from one plant to the stock of another, so as to induce an organic union between the two, are frequently spoken of as "ennobling." This term suggests the nature of the results obtained in grafting or budding as contrasted to the outcomes found in parasitism among plants. The plant or tree from which the bud or graft is taken is usually of a better quality than that of the stock that receives it. It is either from a valuable type of fruit tree, or a peculiarly fine ornamental shrub, which the gardener desires to perpetuate, improve or increase. He chooses his stock from a strong, healthy growth of an individual plant belonging to the same class as the bud or graft he is to transfer, but of a wilder species. It is, therefore, often spoken of as the wild stock, in contrast to the term noble scion, applied to the bud or graft. The whole process is termed ennobling, because it enriches the qualities and character of the growth from the stock.

Though there is measurable success in these processes, there are limits to its possibilities. Not all shrubs and trees can be made to unite with each other.



After two weeks in a root propagator, where they were kept constantly moist, these begonia, achyranthes (tropical herbs) and ivy cuttings all exhibit a very definite root development.

Rutgers University

In order to have any certainty of a successful result, the graft or bud and the wild stock must have racial affinities more or less close; that is to say, the process is most certain and most successful when carried out between members of the same family or genus. Hence we find that it is quite easy to graft plums, apricots, almonds and peaches one upon the other, as well as pears, apples and quinces, all these plants being closely allied in origin. But statements that peaches can be successfully grafted upon willow stocks, or that the Siberian crab has sprung from the grafting of branches of the pear upon the willow, and other similar stories, may be relegated to the realms of fiction without further consideration.

HOW NATURE HEALS A TREE'S WOUNDS

As would be expected from the fact that the juices in the wood of the stem are conducted directly into the tissues of the grafted portion, there is a certain amount of alteration in the character of the two portions subsequently. The pear grafted upon the quince, or other stock, always remains a pear, and retains its own special characters — those for which it is being grown. It is, nevertheless, true that the pear-tree resulting is altered in certain minor directions and, indeed, that is the whole object in the process.

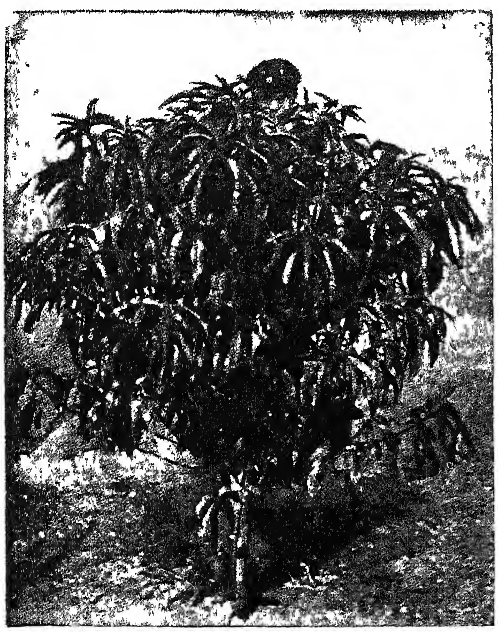
The fruit which results may be larger and of better quality than that of the tree from which the graft was taken, or it may appear and ripen earlier or later in the season. The shape and habit of the whole growth may vary from the original, and all these and other similar variations may be ascribed to the influence of the special nutrition supplied to the graft through and by means of the tissues of the stock. Just why the branch which springs from the graft should behave differently from others is not quite clear, but it is probably connected with some interference with the process of cell nutrition at the exact point of union of graft and stock.

Coming now to details in the process of budding, there are a number of ways both of preparing the buds for transfer and of treating the scions to which the buds are to be transferred. We may take one of the most common procedures as an illustration, as the principles of these methods are the same. A very usual operation among those whose business it is to deal with fruit trees is that known as "shield-budding," which is done best in the months of July or August, since at that time the bark of the stock is easily separated from the wood underneath. This is essential, because it is into the cavity made by this separation that the bud must be inserted. The buds themselves, which are wood-buds, are taken from the fresh shoots of that year's growth, and should be neither too young nor too old. This is provided for by taking the bud from about halfway up the shoot — that is, where the wood is about half ripe.

The operator having selected the bud which he is about to use, cuts it out of the young shoot, along with a piece of the bark, this piece being in the shape of a shield, hence the term "shield-bud". The incision made in doing this is sufficiently deep into the shoot to carry away with it a very small piece of the wood, and this is carefully pulled off from the bark and thrown away. This is the most delicate part of the whole business, because in pulling away this portion of wood one is apt to tear with it the axil of the bud, leaving a depression, and making the bud useless.

Having, however, successfully avoided this danger, the leaf in the axil of which the bud is growing is also cut off, and the bud is now ready for inserting into the bark of the stock.

The cut in the stock is made in the shape of the letter "T," and the bark raised a little on either side of the incision. The bud and its shield are then inserted into the aperture so produced, and the folds of the bark allowed to fall back over the sides of the shield, which they thus maintain in position. The whole thing is then firmly secured either with raffia or some other binding material, leaving only the tip of the bud exposed. If the bud has not been damaged during this operation it will be firmly united and the wound healed in the course of two or three weeks, at which time the bandage or binding can be safely removed. If there is any reason to think that the growth is not yet thoroughly established it may be left for a month. The only other point to which attention is necessary is to see that no other growth is allowed to occur from the stock that season, except the bud. That is, the object is to direct all the nutrition of the stock to the site of the new growth.



RESULTS OBTAINED FROM SINGLE BUDS ON A NEW ZEALAND EXPERIMENTAL FRUIT FARM

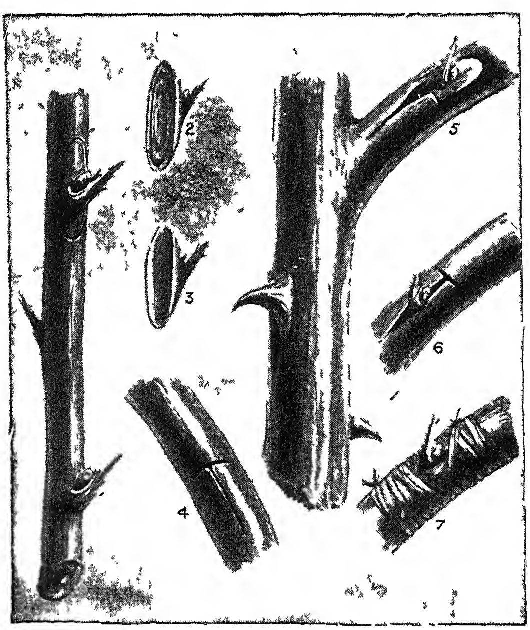
A peach-tree, one year's growth from a bud.

An apricot-tree, three years' growth from a bud.

Whenever the surgeon, be he animal or plant surgeon, makes an incision into the tissues of his patient, this is followed in due time by what is known as the process of "healing". In animal tissues the ultimate result of this process is familiar to all of us in what we know as a "scar," and the process of healing up in a surgery of every wound in plants is very similar, and somewhat analogous. Here, too, we have a scar produced, such as may be seen on the boughs of almost any tree, and this healing tissue, or "callus," is formed by the cambium of the stock and the cambium of the transplanted bud, these two becoming intimately and organically united.

Coming next to the actual operation of grafting, it may be remembered that the design here is exactly the same as that in the process of budding, namely, the ennobling of a portion of one plant by inducing it to grow by means of the nourishment supplied to it by another. As in the case of budding, an original stock, either wild or otherwise, is required, and this has to be treated in such a way that the cambium layer of the vigorously growing stock can be brought into intimate and accurate apposition with the same layer of tissue

in the portion of plant which is to be grafted, so that these two different tissues will ultimately so grow together as to form one single stem or branch In order to do this the stock upon which the graft is to be placed is cut off entirely in a transverse direction, leaving a circular flat surface. An incision is made into the margin of this transverse section, and if necessary a portion of the tissue of the stock may be actually excised. The graft or the scion which it is proposed to implant on the stock is then inserted into the aperture so made, the greatest possible care being taken to make sure that the different layers in the one correspond exactly in position to those of the other That is what is meant by saying that the two must be placed in accurate apposition. In this matter the plant surgeon acts in exactly the same way as does the human surgeon, who in stitching up a cut he has made in the body of his patient takes the greatest care to see that similar tissues are joined together He stitches skin to skin, mucous membrane to mucous membrane, and so forth, because he knows that only by so doing can he get a good, sound union without an unsightly scar. So that here, again. we see that the principles which underlie these interferences with plant and animal life — all these surgical operations — are essentially the same.



THE METHOD OF SHIELD-BUDDING

1, Line of cut; 2, bud cut out, 3, woody part removed; 4, incision in stock, 5, end partly inserted, 6, end fully inserted, 7, method of binding up

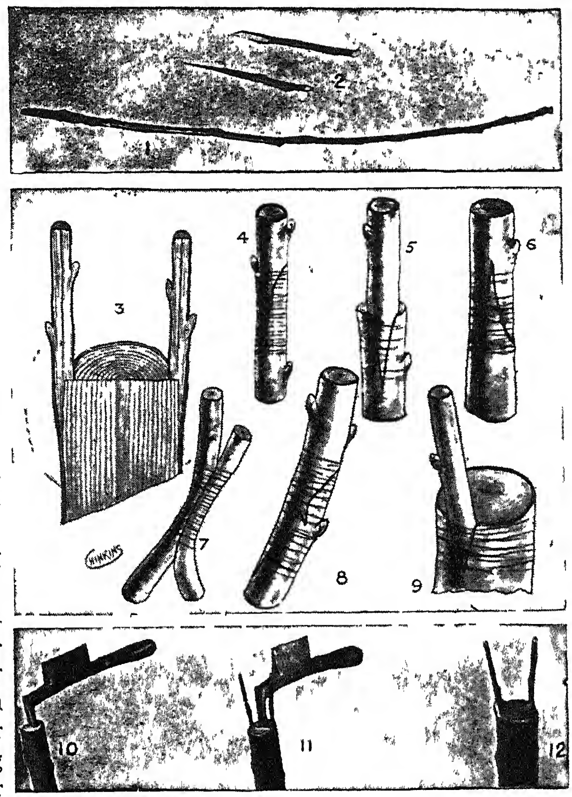
The scion, or graft, which has been carefully prepared and trimmed so as to fit exactly into the portion of the stock made ready for it, should bear at least two buds, which should both be perfectly healthy. When the insertion has been made — that is, when the scion has been dovetailed into the stock, much as the handle of a tennis racquet is dovetailed into the head — the wounds caused by the operation are covered up, as the human surgeon dresses his wounds, by some material which will protect the cut surfaces and aid in the union between the two tissues. Such material usually consists of wax, putty or of some similar compound.

Examples of the manner in which this operation is carried out will be seen depicted in the illustrations in this chapter, which show exactly how it should be done. If the operation has been successful, there will be formed an actual organic union by means of continuity of tissue between the graft and the stock. This union will allow of the passage of nutritive juices from the stock to the scion by means of which the life of the latter will be maintained, and not only the life but the growth, as will be evidenced a little later on when the buds on the scion develop into actual branches.

This process of the growth of the graft does not necessarily mean that the growth of the stock ceases. Indeed, it is quite a common thing to find that while the grafted scion is producing its own branches at the top, the original stock is also sending out branches down below. In this way the curious sight is sometimes seen of what appears to be one plant or tree bearing two entirely different fruits, or blossoms, or leaves, in different parts of it. So one may find, for example, medlars coming to maturity as a fruit in the upper branches, while quinces are forming down below. The medlars represent the fruit of the graft which was joined by the pro

cess of grafting on to the quince stock, which has been allowed to produce branches also. We need hardly say that this is not the ideal result for the fruit-grower, who carefully removes signs of the lateral growth from time to time, in order that all nutrition may be sent to the graft itself, which is the portion of the tree that he specially values.

Before we leave these interesting processes of budding and grafting and so forth, one or two words must be said upon the much-disputed subject of graft-hybrids. A hybrid is a plant produced from two original parents which have different properties and characters, the most ordinary way of producing such a plant being by making a cross between the two by transferring the pollen of one to the stigma of another. The resulting plant, the hybrid, differs from both the original parents, being either midway between them in character or approximating actually to one or to the other.



METHODS OF GRAFTING

1, A good piece of scion wood, 2, two scions ready for use for top grafting, 3, section showing crown or rind grafting, 4, splice grafting, 5, cleft grafting, 6, saddle grafting; 7, marching, 8, whip grafting, 9, notch grafting; 10 and 11, stock split and held open for reception of scions, 12, scions in position, wax having been applied

It will be observed that this process of hybridizing depends upon the union of germ-cells. Now, it has been repeatedly asserted, particularly by practical gardeners, that a hybrid plant can also be produced by budding or grafting, and such a plant is termed a "graft-hybrid". One such plant of the laburnum group (*Cytisus Adami*) has occasioned considerable discussion in botanical circles. It shows a curious mixture of the features of an ordinary yellow laburnum and the purple laburnum. Most of the flowers appear to be equally like both parents, with some minor differences. The corollas are of a dirty red color, suggesting the mixture of the purple and the yellow. But the strange thing is that on some of the branches there are a few blossoms having yellow corollas, others having half yellow and half purple, or other combinations and proportions. This tree is said to have been produced in Paris in 1826 by a grower named Adam, who inserted a bud of a purple laburnum into a stock of the ordinary yellow type, the resulting ingrowth having characteristics derived from both. From this plant buds were sent all over Europe. The most interesting fact stated concerning it is that not only do the cuttings from the original graft-hybrid of Adam bear flowers of an intermediate character, which one might expect, but that some branches show other flowers which revert back to the type of the parents, while single flowers have half the characters of one parent and half of the other. Thus this graft-hybrid bears three distinct kinds of flowers, as combinations of the two parent forms.

We have not space here to enter into all the details of the controversy which this curious state of things suggested, but it may be well to mention that the careful consideration of analogous cases in other plants, particularly in connection with the

experiments made on the iris, have led many to the opinion that this graft-hybrid of the laburnum was originally not a plant of that kind at all, but was a true cross between the yellow laburnum and the purple one. That is to say that the original plant of Adam was not obtained by process of grafting, but by a true hybridizing or cross. Still, the point is by no means settled; and quite recent experiments in other directions show very curious mixings of parent characters, though not fusion of such. What is required, before definite judgment can be arrived at, is the knowledge of whether or not the sum total of the characters of Adam's graft-hybrid are absolutely unique among hybrid plants whatever their origin may be.

Botanists do not all deny that such a thing as a graft-hybrid can be produced, because there is no reason to say that the protoplasm within the cells of the stock of the graft may not undergo a certain amount of fusion or mixture. If such a thing did happen one would then have a protoplasm in the cells of the graft having a character of neither of the two parents, but of an entirely new type—namely, its own. If such intermediate form of protoplasm were produced, then one would be prepared to find the curious mixture of characters which is asserted to have been produced in Adam's graft-hybrid.

P. W. Zimmerman and A. E. Hitchcock recently showed that certain chemicals (indole and naphthalene substances) inhibit the formation of shoots but induce roots from the same tissues. Various acids and esters were physiologically active when applied not only in solution but also in vapor form. The response induced with these growth substances is of a formative nature, usually affecting particular organs or parts of a plant, and differing in this respect from fertilizers. Downward growth of leaves, enlarged stem tips, positive geotropism of stems, enlarged growths, and induced roots are examples of formative effects which are called "induced abnormalities."

THE WILY WEASEL FAMILY

A Vermin-Destroying Family of High Value as Such and for Their Furs

WHY HAVE WE CEASED TO TAME THE WILD?

THE fur-bearing, or weasel family (*Mustelidæ*) is widely distributed, being spread over the whole world except Australia and Madagascar. It includes an extensive variety of animals besides the weasels proper and their near relatives, the martens, sables, polecats, minks, pekans, etc., including the badgers, grisons, wolverines, ratels, skunks, otters and many less known species. These are the animals that give us the most precious of our furs — the sables so celebrated in the annals of the rich, and the ermine about which clusters so much of royal history; while the pelt of the sea-otter is by far the most costly one in the fur market. The sable is Siberian, the pine-martens belong to northern Europe and Canada, and the ermine is any weasel in its white winter dress.

The pine-marten, or simply "marten" as it is known in Canada, has a body length of from sixteen to eighteen inches; it has a tail of from ten inches to a foot; it climbs with remarkable address both trees and rocks, and easily scales, in Europe, the smooth, perpendicular posts that support the dovecots it delights to raid. Although mainly arboreal in their habits, pine-martens descend to the ground to prey upon hares, rabbits and smaller animals, and they will even attack both poultry and lambs.

In Canada the pine-martens nest usually in the hollows of forest trees, but they are out and wandering abroad all winter, traveling easily over the snow and feeding on hares and squirrels. They are trapped from November until March; and are now restricted by persecution to the distant forests, although originally they inhabited the woods as far south as the central United States. The habits of the Siberian sable are substantially the same, but it is said to feed largely on berries.

A still larger marten of the Old World, ranging from Germany to Asia Minor, is the beech-marten, or stone-marten, whose skin is often sold as a sable. It is larger and lighter in color than the true sable. While the pine-marten is exclusively carnivorous, the beech-marten has developed a taste for fruits of various kinds, so that it has become necessary in some parts of continental Europe to spray the trunks of fruit-trees with tobacco juice and petroleum, the odor of which the animal finds intolerable.

Another very interesting species of this group is the American Pennant's marten, which the Indians named "pekan" and the trappers call "fisher" or "black cat". It is of great size — 24 inches in length, plus 13 inches of tail — and has a dog-like head. It has never been numerous, and now is to be found only in the backwoods of Ontario and Quebec. It prefers wet to dry woods, and keeps more to the ground than do the others, yet is wonderfully strong and agile in tree-tops. Its strength, indeed, enables it to seize and devour such large creatures as the musk-rat, skunk, raccoon and porcupines; and it is sometimes able to force its way into a beaver-house. It is sought by the fur hunters less for its thick, dark pelt (although that is valuable) than because it is a persistent robber of the traps, not only cleverly stealing the bait but devouring any prey caught in them.

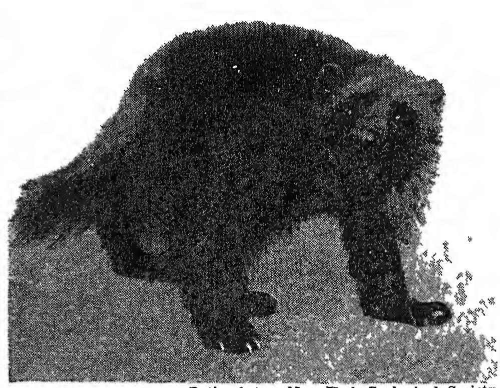
A still worse nuisance to the hard-worked trapper, however, is the animal called a glutton in northern Europe, and wolverine, or carcajou, in Canada, where it lives from ocean to ocean. The wolverine is the largest of the weasel family, equaling, in the adult stage, a small bear, and differing from other weasels in that it stands fairly high upon the leg. The wolverine not only robs the trapper of both his bait and catch, but such are its skill and craftiness that it is almost impossible to trap. It shows an uncanny guile in eluding the artifices of the despairing trapper. It preys upon all small mammals, including the beaver, and will pull down a wounded or sick deer.

This streamlined grison hunts small mammals and birds. When it is attacked or cornered it exudes a fetid odor similar to that of a skunk.

Like certain birds and other animals, the wolverine combines an enormous appetite with a strange kleptomania. It will creep into the unoccupied tent of the trapper and carry away and bury every portable article that is available, from a gun to a blanket. All things considered, the wolverine is a considerable trial to the trapper, and there is no animal that has made a more audacious and cunning fight against man and his arts in the wilds than this lord of the wily family of weasels.

Two smaller but very troublesome and savage members of this family are the tayra and the grison, both belonging exclusively to Central and South America. The first matches the otter in size; the grison has more the proportions of the marten. Both frequent hollow trees, clefts in rocks, and the deserted burrows of other animals; both prey upon various small mammals and birds. Eggs play an important part in the diet of the tayra and the grison.

The true weasels are distinguished from the martens by their small size, slimness of body, preference for the ground — although all are good climbers — their close fur, comparatively short tails and change of coat in winter. Several species inhabit the Old World, of which the most familiar is the stoat, or true ermine weasel; and several others belong to North America. One species ranges south along the Andes. The specialists tell us of more than twenty species in North America, but the best-known are the common, or short-tailed, weasel, the northern long-tailed weasel, the little "mouse-hunter" of the northern plains, and the bridled weasels of the Pacific Coast, marked with a black band across the face. The Arctic coast has another species very like the stoat. But wherever the weasel is encountered, he is found to be "a keen, agile, indomitable hunter, within his powers a being of the highest type of effectiveness."



Both photos, New York Zoological Society

The wolverine is unequaled by any animal in courage and craftiness and is reputed to be the most powerful mammal of its size in existence.

FIVE MEMBERS OF THE WEASEL TRIBE

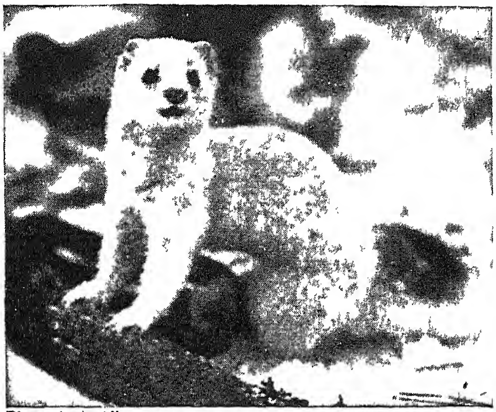


Photo A A Allen

A NEW YORK WEASEL IN WINTER PELAGE

THE EUROPEAN BADGER

THE FERRET — A TRIUMPH FOR MAN'S POWER OF TAMING

THE AMERICAN BADGER

A YOUNG CANADIAN SKUNK

What these powers are may be seen in the following paragraph from THE FUR-BEARING ANIMALS by Dr. Elliott Coues:

"Swift and sure-footed, he makes open chase and runs down his prey; keen of scent he tracks them, and makes the fatal spring upon them unawares; lithe and of extraordinary slenderness of body, he follows the smaller through the intricacies of their hidden abodes and kills them in their homes. And if he does not kill for the simple love of taking life, he at any rate kills instinctively more than he can possibly require for his support. Yet which one of the larger animals will defend itself or its young at such enormous odds? A glance at the physiognomy of the weasels would suffice to betray their character.

New York Zoological Society

The savage, weasel-like tayra of South America.

The teeth are almost of the highest known raptorial character; the jaws are worked by enormous masses of muscles covering all the side of the skull. The forehead is low and the nose is sharp; the eyes are small, penetrating, cunning and glitter with an angry green light. There is something peculiar, moreover, in the way this fierce face surmounts a body extraordinarily wiry, lithe and muscular."

The fur of all the true weasels — in summer, light or dark brown above and white, sulfur yellow or orange, according to species, underneath — becomes white in winter wherever the climate is such that snow remains continuously from late November to April. South of the line of permanent winter snow the weasels keep their brown color all the year round, but along this climatic borderland they may become partially winter snow the weasels keep their brown is the valuable ermine — in the Middle Ages a symbol of royalty and later so distinguished a mark of high office on the judicial bench that we still refer to a judge as a "wearer of ermine." The weasels are of great service in destroying vermin in the fields and in hunting rats and mice about barns and storehouses, and these activities should be encouraged.

The mink, on the other hand, is of little value to man except for its fur. Minks exist in northern Europe and are encountered over all the North American continent. The mink is larger, stouter and more robust than the weasel, and its fur is everywhere thicker and darker brown in color, except for the white patch of variable extent on the chin. It lives on the ground, making its den in holes under or inside old stumps, in crevices among loose rocks or in burrows usually opening in the bank of a stream or lake. It hunts its food mainly along stream and lake shores where it preys upon frogs, fish (especially eels) and other aquatic animals. Though trapped by amateurs and professionals alike, it holds its own in even the most thickly settled regions. Mink farms are now a successful enterprise throughout the northern United States and Canada. The mink are as carefully raised and tended as though they were precious children, which in a sense they are. Most mink skins for fur coats now come from these farms.

The polecats, apart from certain structural differences, are distinguished from the martens by the fact that while the martens are inoffensive in the matter of odor, they are equipped with a notoriously evil fluid for confusing their enemies. The name "pole," or "pol," as it was originally spelled, may be a corruption of the French *poule,* a hen, in reference to the animal's great weakness for poultry. Or it may come from the old English word *foumart,* or "foul marten," referring to its fetid odor.

THE POLECAT, FROM WHICH THE FERRET HAS EVOLVED

In many parts of Europe and in Asia, polecats of various species are common. Though they vary in size and coloration, their habits are similar, their defensive odor abominable. To have evolved the ferret from the polecat is a distinct triumph for man. In this animal the offensive scent has been largely destroyed, while, as has been mentioned, the power of the animal to multiply has been increased. It would be interesting to see whether the domesticated ferret, if liberated, would revert to the characteristics of the true polecat. There is little likelihood of the question being answered, for even the long period during which the animal has been domesticated has not removed it from suspicion. It has been kept simply as an aid to the hunting either of rabbits or rats. Like all the members of the weasel tribe, ferrets are incorrigibly bloodthirsty. A couple of them will kill more than a hundred times their number could eat, and their almost insatiable passion for blood must be the explanation. And even the oldest and most experienced ferret must be muzzled before being turned into a rabbits' burrow, or it would remain there to drink the blood of the first victim it chanced to hunt down.

Courage and power are attributes of every member of the weasel family, and in none do we find these qualities more pronounced than in the ratel, an Indian and African representative of the tribe. Ratels are very badger-like in build, and have powerful claws, with which in time of danger they can sink themselves into the ground with astonishing celerity. It is this that has given the animal the name of the "grave-digger," for it is asserted that the ratel is a robber of graves. The accusation appears to be wholly unjustified.

THE AMUSING BUT UNTRUSTWORTHY RATEL

The food of the animal consists of honey and the larvæ of bees, termites and small mammals. The ratel is another member of the weasel family that is successfully domesticated. In captivity it makes an amusing companion, trotting about with great activity, and turning somersaults to attract attention. But, beware of the ratel; it bites upon the least provocation, not, apparently, from malice, but, like a squirrel unhandily grasped, from fear.

Specialization reaches its highest point in the American skunk, but it is a specialization accompanied by degeneration. It is equipped with glands from which it can at will discharge a fluid as vile as asafœtida — a fluid that destroys the sight, and overcomes man or animals with nausea. Conscious of its vile powers, the skunk has abandoned all other means of defense. It has become a lethargic robber, and makes no attempt to escape when attacked, or to defend itself with its powerful teeth. The secretion that makes the animal notorious is produced from two glands near the root of the tail. In attacking, the skunk turns upon its enemy, raises its tail, and discharges its fluid with considerable accuracy for, if need be, a distance of from twelve or more feet. So powerful and persistent is the odor that a single drop on a man's shoes has been known to stampede the whole of the company from a ballroom.

More engaging members of the family are the badger and the otter. The former is capable of fœtid exudation, but this is not for purposes of defense so much as a means whereby badger may track badger; and the tame badger is regarded as quite innocuous and cleanly. Like the ratel, the badger is loose-skinned, so that when seized by the hide it can readily turn and inflict an unexpected and ferocious bite.

It was because of the animal's courage, its power to inflict severe wounds, and to withstand them in its own person, that the badger was for long the victim in England of a brutal sport known as badger "drawing" or "baiting" where a dog of courage had to go into the animal's improvised retreat and force it into the open. This "sport" has now given place there to one scarcely less wanton, in which "gentlemen" set their hirelings to dig out the animal, while their dogs wait to rend it in pieces as soon as it appears. The badger always makes a good bid for his life, first in flight, afterwards in fight.

It is not until man sets to work to dig out the badger that he realizes the excavating powers of the animal. The badger can bury itself in from sixty to seventy seconds; and while the man with pick and shovel is tearing away at the burrow, the beast industriously excavates in the interior, extending its run, and building partitions of earth across the tunnel to prevent the ingress of dogs. Badgers and foxes have been known occasionally to share two sections of one burrow.

NOBODY'S FRIEND: THE PERSECUTED OTTER

What has been said so far refers to the badgers of Europe, but a very similar one inhabits the United States and has similar wild habits. It was formerly found throughout all the open country from Ohio to the Pacific Coast, and north-westward to Peace River. It has suffered so much from the civilization of the land and the greed and hatred of settlers that now it is rare except on the remote western plains. This persecution is a great mistake for, as in the case of the mice-hunting skunk, the animal is of vast service in keeping down the ever-increasing population of field-mice, gophers and ground-squirrels that are so destructive a pest to farmers. The badger should be cultivated rather than persecuted, and his digging of holes (the only real harm he does) may well be forgiven.

The otter is a member of the tribe that has made itself master of an aquatic life, and is such an interesting and handsome creature that we ought to be proud to preserve it. It lives in the main upon fish, it is true, and in England, where

angling rights are more precious than in America, it is hated as a fish-eater and hunted for "sport" with trained dogs. In America, unless it gets into a hatchery, it is neither; indeed it is too rare and shy for the latter. Once it inhabited in small numbers almost every stream on our continent; but it has become rare now except in the wild North, where its beautiful pelt is sought by fur-hunters. In its general manner of life it much resembles its European cousin.

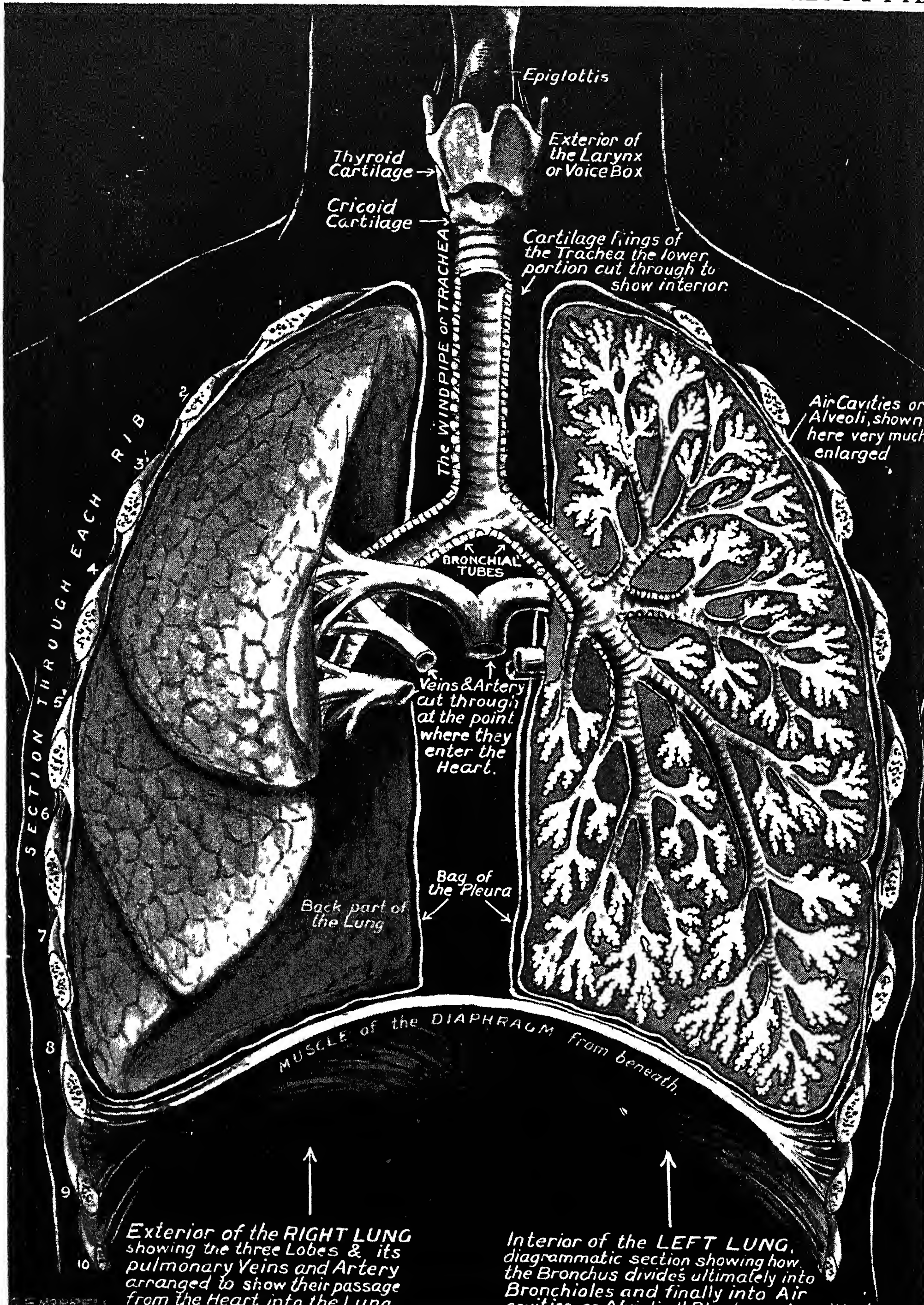
Left to itself, the otter rests for the greater part of the day in its "holt" near the stream, and comes out at night to feed. Under ordinary circumstances, careful watchers assert, the fishes that the otter takes are small or diseased. It has only the night in which to catch fish for itself and for its young, and has no time to waste in useless chase of big, fleet fish. Instead, therefore, of depleting a stream, it keeps the water free of disease and is, so the otter's friends argue, an actual benefit to a fishery. When winter's cold locks up the water, the otter may be driven to turn its attention to life on land, and at such times may attack poultry and even game.

A VANISHING SPECIES: THE COVETED SEA-OTTER

No animal is more readily educated than a young otter. It is naturally a playful beast, and its slides down the soft soil of a river bank or in the snow are well-known features of its habitat. In captivity it shows all its natural playfulness and affection towards its master. It is readily taught to follow like a dog; it will enter the water and leave at the word of command. When it is to be instructed in the art of fishing for another it is first broken to a diet of milk and bread and other things. Then it is taught to retrieve things on land, and afterwards made to fetch and carry a dummy fish, which is thrown into the water. Then comes the catching of a real fish cast into a stream. If the otter eats the fish, it is rebuked; if it brings it to its master, it is rewarded. In this way it soon learns its lesson, and comes to be a first-class helper in the catching and bringing in of fish snatched from the stream.

Otters take readily to life on the seashore, but these must not be confounded with the true sea-otter of Alaska, which, as our illustration shows, is quite another animal, and more seal-like than its congener. The sea-otter is referred to a genus apart from the other otters, as is bound to be the case when we consider the structural differences between the two animals. The long hind legs of the sea-otter are a kind of glorified example of the seal's flippers, and the fore limbs are very short. It is to be feared that there will not be much opportunity in the future for us to become familiar with this animal, for so highly esteemed is its fur that it has been almost exterminated in spite of the extraordinary acuteness of its sight and hearing. The bludgeon, the rifle, and the net have been too much for it. It was driven from its breeding-places on shore to banks and masses of floating weed, but the hunter still followed; and today so scarce has the animal become that a sea-otter's skin brings a very high price. A sort of attempt has been made to domesticate this animal, but such is its mortal dread of man that the young ones captured have died, as much from terror as from the want of the food that fright prevents them from taking, an ending sadly in keeping with man's relations with all the wild creatures we have grouped in this chapter.

THE ORGANS WITH WHICH WE BREATHE



This picture-diagram shows the two lungs as they are placed in the chest, the encircling part of the ribs being omitted for clearness. The right lung is shown complete, with its three lobes, and the left lung in section. An inspiration has just been taken, so that the chest is distended and the diaphragm flattened somewhat, exposing the large extent of the back of the lung. The front part of the lung is slightly pulled aside in the drawing to allow us to see more clearly the entrance of the artery and the exit of the veins which carry the blood to and from the lungs.

THE RESPIRATORY SYSTEM

How and Why We Breathe with Unconscious Regularity, and with What Results

HOW THE BRAIN AND BODY ARE VENTILATED

THE body of man is an animal; the characteristic organ of the body, looked at simply as an animal, is its brain; and this brain is the throne of Man. Before we can proceed, then, to a study of the machinery and substructure of this brain, we must first study the other systems and organs of the human body, for without them man's marvellous and delicate brain would be to no avail.

We come, therefore, to the system which exists in order to ventilate the brain and those other parts of the body that, in one way or another, serve the brain. In this fashion we shall gradually climb up the animal to man himself, who is our real business in this section.

As for the respiratory system, we may remind ourselves that all living things breathe, and that the microbe and the amœba and the alga must have a respiratory system, no less than man has — though visible machinery may be absent; and, further, that the structures which we describe in man's body are to be found, in all essentials, no less well developed in a multitude of other species. They are in no sense characteristic of man, but they mightily concern him, for his brain and body must be ventilated, and this is the indispensable function which they serve.

Primitive organisms breathe by their whole surface — that is to say, the interchange of gases, which is the essence of breathing, occurs wherever the body and its gaseous environment meet. Somewhat higher organisms invent special machinery, but can breathe more or less through the skin. But man, like his nearer allies in the animal world, takes in air almost exclusively by a special channel. This intake of air we call breathing, or respiration. But it is obviously only the mechanical preliminary to the real breathing, or "tissue-respiration," which occurs in the living cells of the body everywhere, and for which what we commonly call breathing exists.

The real parallel to the breathing of the amœba is that of the white cell in the blood, which helps itself to oxygen therefrom, just as the amœba helps itself to oxygen from the external atmosphere. In effect, what we call breathing, together with the circulation of the blood, exists in order to provide every living cell of the body, in the upshot, with an immediate environment of oxygen, such as the amœba has; and this arrangement is so completely carried out that even the cells of the skin, which are next the external atmosphere, breathe not the oxygen therein, but the oxygen that is brought to them by the blood from the lungs.

The air, or wind, is conveyed into the interior of the body by the windpipe, or trachea, of which anyone may feel the upper portion just below the larynx, or voice-box. In order that the man shall live, it is absolutely essential that a sufficiency of air shall pass down his windpipe, and a sufficiency of different air return. How the air gains admission to the pipe is a secondary matter — of high importance, but secondary. In certain circumstances a hole may be made in the windpipe, or trachea, and may be kept open by a tube, and may suffice for an indefinite period — even extending to months or years.

This operation of tracheotomy was incessantly performed, and saved life, before the introduction of the diphtheria antitoxin, and is still required at times in various cases. If anything becomes impacted in the larynx, an emergency opening may be made by a penknife or what not between the large projecting cartilage of the larynx and the ring of cartilage just beneath it. This laryngotomy may thus permit the continuance of life. Scarcely more normal than the entry of air to the windpipe by a hole in itself or by a hole in the larynx is its entry through the mouth, as in "mouth-breathers." The mouth may, however, be admitted for this purpose in forced respiration, as in violent exercise. But the bodily apertures constructed for respiration are the nostrils, and the nostrils alone.

VOCAL CORDS, CLOSED IN SINGING AND OPEN IN BREATHING

They are the beginning of the respiratory system, the end of which may be named in the air-chambers of the lungs or, more logically, in the actual cells of the body everywhere in which the act of tissue-respiration is consummated.

The air entering the nose is warmed, moistened, and largely filtered both of dust and microbes. It passes freely through the throat, from the back of the nose to the opening of the larynx, cutting, however, across the path of food or drink to the gullet. This is a source of some danger to the body, and kills a certain small proportion of mankind by choking.

In all but one in a thousand cases of choking, however, the trouble is not mechanical but spasmodic. Some drops of fluid, probably, have entered the larynx and set up irritation. The vocal cords well know that no food or drink should enter the larynx and reach the lungs. They tightly close the aperture to make further entry impossible. This involves temporary suffocation, with its inimitably horrible sensations; but it is absolutely certain that, just so soon as the carbonic acid in the blood mounts up a little, it will paralyze the spasm of the vocal cords, which will relax, and in a fraction of an instant he who could not breathe at all will be inhaling a full flood of air. Those who know and understand the sequence of events, in this fashion, suffer much less when they choke, as they are freed from the sense of impending death, knowing that the cords will relax in a few seconds.

The presence of the larynx with its cords, and the very narrow gap between them at the top of the windpipe, is a modern adaptation for speech. It has nothing to do with respiration, save only that respiration involves the movement of air, and sounds are made in air. This is another instance of the inventiveness of life, but need not be discussed further until we come to consider human speech — the great achievement of the human brain — and its vocal instrument, the larynx.

The windpipe is unlike nearly all the other tubes of the body in that it is always open. We think of the gullet, and many other tubes, as permanently open. But, in point of fact, their walls are in constant apposition except when something is passing along them. It must be remembered that the whole of the body is subjected to the pressure of the atmosphere, and there can be no such thing as a merely vacant tube in it. But the trachea requires to be constantly open, and for this purpose its walls are stiffened by the rings of cartilage, the first few of which we can readily feel in the neck just below the larynx. The tube is lined throughout with cells of a peculiar type, equipped with what are called cilia — or "eyelashes," as the word means. These ciliated cells have the function of constantly lashing upwards any fluid that may be in the larynx.

The ciliary motion is invariably upwards — towards the mouth and nostrils, just as the ciliary motion of the similar cells in the nose is always downwards, again towards the nostrils.

Not only fluid, but a great deal of solid matter, dust and microbes, is caught in the sticky secretion of the interior of the trachea, and then whipped upwards by the cilia. We note about ciliary motion, here and elsewhere, that it is totally independent of nervous control, unlike the motion of muscle cells, striated or non-striated. The same is, of course, true of the motion of the leucocytes, or white cells, of the blood. Both white cells and ciliated cells move independently of any central orders or direction, but none the less in orderly fashion and wholly for the service of the body. We note, also, that ciliated cells and white blood-cells both closely resemble humble forms of animal life such as we find in ponds.

In tracheitis, or inflammation of the trachea, such as always accompanies bronchitis, or inflammation of the bronchi — which are the further divisions of the trachea — the ciliary cells are all shed, for the time, leading to stagnation of the secretions, and the irritation which shows itself in the need to cough.

The trachea divides into two, forming the right and left bronchus, one for each lung. This subdivision continues, the vessels becoming smaller and smaller, until they are called "bronchioles". In essentials, the structure of this tree-like arrangement is the same throughout, but the proportion of cartilage gradually diminishes, and unstriped muscular tissue becomes conspicuous in the walls of the smallest tubes, which have no cartilage at all. We here see a parallel to the case of the blood-vessels,of which the largest have a high proportion of fibrous "stiffening," so to speak, with very little muscular tissue; while the arterioles, like the bronchioles, consist of little more than muscular tissue. In the case of the arterioles, their muscularity has an evident function; but there does not seem to be any evident reason why the quantity of air going to any particular part of the lung should be controlled, and, indeed, all we know of the muscular tissue of the bronchioles is little to their advantage. This tissue is, of course, under the control of nerves, and, being non-striated, is involuntary.

Only too often the tissue is thrown into contraction unnecessarily, producing the "nervous asthma" which, in time, gravely injures the value of the lungs by interfering with the act of expiration, and leading to stretching of the elastic tissue that abounds in the lungs, and is so necessary for their healthy functioning.

All that we have described so far is, of course, no more than a system of ducts. The essential lung-tissue, to and from which they convey the air inspired and expired, is packed all round them — a spongy, highly elastic tissue, always with air in it, and very richly supplied with

THE AIR AND FOOD PASSAGES
Showing a lump of food lodged at the top of the windpipe, causing choking

blood-vessels. The lungs of an infant which has never breathed will sink in water, but if only one breath has ever entered lung-tissue it will always float, a quantity of air remaining in it even after the utmost effort at expiration.

We are to understand, then, that the ultimate divisions of the windpipe lead to a vast multitude of air-chambers, each somewhat expanded around the end of the tube which it caps, rather after the fashion of a child's collapsible balloon. The lungs are simply an enormous number of such expansible sacs, which can be filled and emptied alternately; and the air as it leaves may make sounds, as in the "dying pig," or in the human larynx.

There is a difference in the manner of filling, for the air is forced into the child's toy, while it is sucked into the lungs — the one requires a force-pump, and the other a suction-pump; but both alike are normally emptied chiefly by the inherent elasticity of the material of which they are composed.

The lungs a device for purifying as much blood and as fast as possible

Imagine now a very close and very fine network of tiny blood-vessels spread over the child's balloon, with blood always running through them, and the parallel is complete. Certain gaseous substances will be liable to pass through the membrane, in both directions, altering the composition of the blood and of the air in the sac respectively; and that is exactly what happens when we breathe. If we can imagine a huge bag of this kind, with an area of some two thousand square feet, it would represent, essentially, the structure and arrangement of the two lungs. They are simply devices for rapidly and continually exposing to the air for purification as large a quantity as possible of blood.

Altered opinion as to the method of purification of blood in the lungs

One structural fact of the highest importance remains to be inquired into. What, precisely, is the kind of partition — or communication, for it is both — that stands between the air and the blood in the lungs? It is very thin indeed. There is first, of course, the wall of the capillary blood-vessel, but that consists of no more than a single layer of flat, thin cells. The lung itself is lined with rather large cells, in a single layer, perfectly flat and very thin. The plump, ciliated cells are not prolonged into the ultimate chambers of the lung. Thus the exchange of gases may take place through what is practically no more than a double layer of thin, flat cells. And we naturally ask how the exchange occurs.

It was long taught, in accordance with the prevailing mechanical philosophy of the time, that the exchange of gases in the lung was entirely determined by those laws of gaseous interchange which apply elsewhere. This statement, and all statements like it, depend upon a confusion of thought. The laws of physics and chemistry are truly universal. Gravitation, to take one instance, acts within the living body, and upon it, and by it, as everywhere else. The laws of gaseous diffusion, and so forth, similarly apply in the body, and it is a legitimate and valuable triumph for science when it can demonstrate the working of these physical laws in the living body. But this is not to say that life does nothing. It is only to say of life what Bacon long ago declared of the highest form of life — which is man — that nature can only be commanded by obeying her. The laws of nature are thus obeyed by life, in order that they may be commanded.

Active part played by cells beyond the passive process of gaseous diffusion

In the extremely important instance now under discussion we have reason to believe that the gaseous interchange in the lung cannot be wholly attributed to the laws of gaseous diffusion, even though those laws are, of course, at work in the lung as everywhere else. A vital part is played by the vital activity of the flat cells which line the lung — cells which, though flat, for an evident reason, are yet unlike such flat cells as those of the skin, for the lung cells have not lost their nuclei, a fact which in itself suggests that their function may be much more than merely mechanical.

Examination of the difference between inspired and expired air shows us what happens in the lung, and corresponding changes are to be found in the gaseous contents of the blood in the pulmonary veins, returning to the left side of the heart, as compared with that in the pulmonary arteries, running from the right side of the heart to the lungs.

We have said "gaseous contents," but it is to be noted that water evaporates, so to speak, from the blood in the lungs, and is added to the expired air. We, in fact, perspire through the lungs. This evapora

tion is remarkably rapid, and we perhaps scarcely realize that the water which condenses again from our breath in cold air in such quantities was actually in our blood a few seconds before. It is very doubtful whether some vital activity on the part of the lung cells is not required to explain this abstraction of water from the blood.

This, observe, is not to say that the laws of aqueous evaporation are abrogated, but merely that we cannot explain the facts on the assumption that the lung cells are inert in the process. The loss of water by the lungs, amounting on the average to about nine ounces daily, is not of the first importance, as the body can also dispose of water by means of the skin and kidneys.

The double purpose of breathing — absorption of oxygen and excretion of poison

Expired air is also warmer than inspired air, assuming that the external temperature is lower than that of the body. Thus the blood loses heat, as well as water, to the expired air, and is very definitely cooled in consequence. The blood going to the body generally, after its return to the heart from the lungs, is thus relatively cool. We shall shortly see where and why it is warmed again, but meanwhile we note that *no combustion occurs in the process of breathing*, as is sufficiently proved by the fact that the blood which leaves the lungs is cooler than when it entered them.

Yet if we closely examine the gaseous composition of expired air we may well suppose that combustion has occurred in the lungs, as used to be supposed. For we find that expired air contains less oxygen and more carbonic acid gas than inspired air, just as if it had been supporting combustion in the lungs. We have seen, however, that the temperature-change of the blood negatives that view, and we find further that the carbonic acid gas has not been made in the lungs at all, but has merely been discharged there as the blood passed through them. Much of the water, and nearly all of the carbonic acid gas in expired air have, indeed, been made by the combustion, or union with oxygen, of hydrogen and carbon, respectively, in the body but not in the lungs.

This will soon be understood. Meanwhile we observe that the removal of carbonic acid gas from the body in expired air is the most characteristic part of the whole business of breathing. The incessant combustion of carbon, with production of carbonic acid gas, is necessary for all forms of life, and it is further necessary that all living things shall get rid of the carbonic acid gas, which is a poison to them. We rightly say that the carbonic acid gas is a food of plants, but the plants decompose it and make sugars of it only. If they absorbed the gas as it is, it would poison them, and a plant requires to be rid of the carbonic acid gas produced by its breathing just as we do.

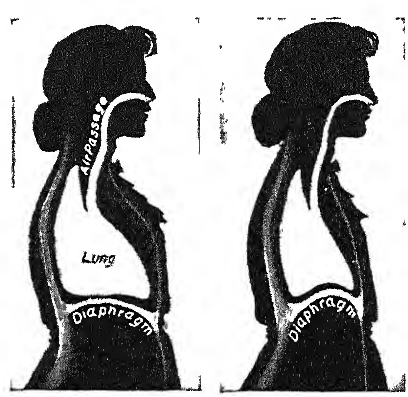
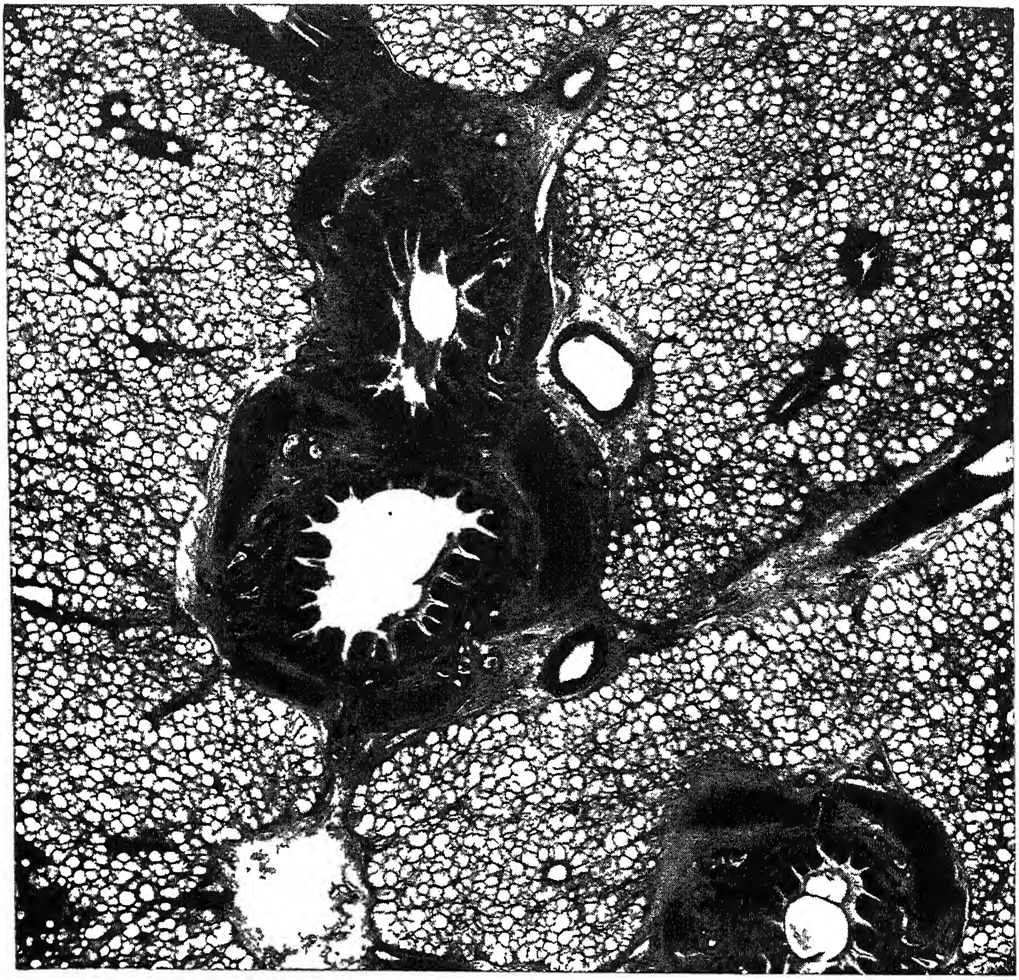


DIAGRAM SHOWING HOW THE DIAPHRAGM HELPS TO FILL AND EMPTY THE LUNGS

We realize, then, once and for all, that the rhythm of breathing is fundamentally different from, say, the rhythm of swallowing. We are not simply inhaling oxygen in successive quantities. Breathing is essentially a double process, partly absorption, partly excretion. The act of inspiration provides the body with what it must have in order to live; the act of expiration rids it of what it must lose in order not to die. This necessary removal of carbonic acid from the blood cannot occur in any degree except through the lungs alone, and the ever-desperate urgency of breathing is above all due to the absolute necessity of getting rid of the deadly poison which the body is always producing within it.

If we die by asphyxia, the cause of death is not oxygen starvation, but carbonic



HIGHLY MAGNIFIED TRANSVERSE SECTION THROUGH A LUNG, SHOWING BRONCHI AND ALVEOLI
The fine pores are alveoli, the large irregular light spot in left center a bronchus.

acid poisoning. It is, indeed, in modern terminology, auto-intoxication or self-poisoning, which is the incessant risk of all forms of life. When a man is compelled to breathe again and again the same air in a confined chamber, he can still live when the proportion of oxygen in his atmosphere is only six per cent, provided that the carbonic acid which he is producing be continuously removed. But if this is not done, the difficulty of breathing becomes extreme when the proportion of carbonic acid reaches five or six per cent, though there may still be as much as sixteen per cent of oxygen in the air. Not starvation, then, but poisoning, is the conclusion of this experiment, and we shall some day learn that it applies equally to the problems of ventilation, and of, say, the want of proper nutrition in the children of the poor.

The pumping arrangement next concerns us. The heart, which pumps fluid from the body, is a force-pump; the pumping of air is done by suction. The lungs are contained in an extensible and elastic box, called the chest. Each lung has wrapped round it a closed, empty, collapsed two-layered bag, called the pleura, of which one side lines the chest-wall, while the other covers the outside of the lung, these two walls being in continuous contact at all times, save when there is pleurisy, and fluid is produced and poured

out between them. When we inspire, we enlarge the capacity of the chest, as "Nature abhors a vacuum," which would otherwise be formed in the pleura By raising its outer from its inner wall, the lung rises with the wall, and air rushes in to enable it to do so In other words, air is sucked into the lung by means of the atmospheric pressure. Each lung has its own pleura, and is independent in this respect. If the chest-wall be pierced, and air is admitted into the pleura, the atmospheric pressure now becomes equal on the inside and the outside of the lung. In virtue of its natural elasticity it instantly collapses. If this should happen to both pleuræ, there can be no alternative to immediate death for the unfortunate individual.

The muscles of inspiration a marvel of finely coordinated mechanism

The enlargement of the capacity of the chest, whereby air is sucked into the lungs, is effected by muscles, and is one of the most important parts of the internal work of the body. The skeleton of the chest is so arranged that the ribs, when raised, increase its capacity. At the same time, a thin sheet of muscle, the diaphragm or midriff, which forms the floor of the chest, and which, when at rest, is convex upwards, becomes flattened, thus increasing the depth of the chest. Like the other movements of the body, whether automatic or willed, this is a concerted movement, employing a combination of muscles in a coördinated way. We thus recognize a group, "the muscles of inspiration," just as we recognized "the muscles of expression" in and near the face.

The intimate relation between wise dress for the body and healthy breathing

The principal muscle of inspiration is the diaphragm, and the next most important are the muscles which lie between the ribs or costæ, and are therefore called the intercostal muscles. In forced respiration a number of other muscles may be called into play, forming the "accessory muscles of inspiration," and their action may be witnessed in various forms of disease, in the breathing of a woman who has as far as possible thrown her diaphragm out of action by tight clothing, or in the breathing of a badly trained singer. The foundation of all good and natural breathing, in both sexes and at all ages, notwithstanding former statements to the contrary, is the use of the diaphragm; and whatever habits of clothing, or of drill, or posture, prejudice or hamper diaphragmatic breathing strike directly at one of the roots of normal living, and materially influence what we call health.

Expiration mainly due to elastic recoil of muscles of the lungs and diaphragm

There are no muscles of ordinary expiration. When the contraction of the muscles of inspiration ceases, the chest subsides, partly by its weight, but mainly by the elastic recoil of the muscles of inspiration, the elastic recoil of the slightly twisted ribs, and, above all, the elastic recoil of the lungs themselves. One of the most subtle and characteristic changes produced in the body as it passes its prime is loss of elasticity. We observe this in, for instance, the lens of the elderly eye, which consequently becomes long-sighted. The same is true of the chest; and the general rule is that our chest measurement slowly but surely increases, as the elastic recoil of expiration becomes less perfect with advancing years.

How our unconscious breathing responds to suggestion from outside

In forced expiration various muscles come into play, muscles far more numerous and varied than anyone could imagine who had not witnessed an asthmatic patient, sitting up in bed and forcing the air out of his lungs through his contracted bronchioles, which should be freely open. These muscles, or some of them, come into play in all the other forms of forced expiration, such as speaking and singing, when the breath is forced against resistance in the larynx; coughing, when it is forced against resistance anywhere in the air-passages; and sneezing, when it is forced against resistance in the inner parts of the nose.

Yawning, on the other hand, is essentially a forced inspiration, due to a suddenly increased activity of the nervous center which we are about to describe. Sighing is closely allied to yawning, and both are efforts on the part of the respiratory center to compensate for the deficient aëration of the blood which must be cleansed of its excess carbon dioxide. The remarkable fact has long been noted that nothing is so infectious as yawning, and nothing more communicative of depression than sighing. Human suggestibility, in a word, is highest to symptoms which concern the most continuous and urgent of human needs, which is to breathe. We cannot have it suggested to us by another that breathing is much required without the oldest center in our own nervous system responding, and we yawn or sigh also, lest we, too, should die for lack of breath.

Quick adaptation of our respiratory system to temporary needs of the body

This respiratory center, or *punctum vitale* — the "vital point" of the older physiologists — is a minute point of nervous matter in the oldest and lowest part of the brain, called the bulb. We shall hear a good deal more about this bulb later, for it contains all the chief centers necessary for the nutritive life of man. The respiratory center ceaselessly controls the whole process of respiration, from the initial breath of birth until the end, maintaining a steady and fitting rhythm. From it proceed the nerves which govern, directly or indirectly, the muscles of inspiration. To it there run nerves from various parts of the body, but chiefly, of course, from the lungs and pleuræ, the larynx and nose, which are able to induce the respiratory center to order a cough, a sneeze, a yawn or any other necessary adaptation to the circumstances of the moment.

But the respiratory center is, above all, sensitive to the blood which flows through it. The nerve-cells are closely aware of the temperature of the blood, and thus induce faster respirations in fever. More closely than this, however, are they aware of the exact proportion of carbonic acid in the blood, instantly making any effort, at any cost to the muscles or to any other part or interest of the body, whenever the proportion of this deadly poison, which the body is ever producing, tends to rise above the tiny quantity permissible. "Eternal vigilance is the price of liberty," and the nerve-cells of the "vital point" know that it is also the price of life.

Principles of combustion simple, breathing of the body extremely complicated

Lastly, we note that all this is merely preliminary to the inner, or tissue, respiration, for which the blood carries oxygen to the tissues, and in consequence of which it carries carbonic acid away from them. There it is that the blood acquires the heat which it partly loses in the lungs, for there it is, in the tissues, and not in the lungs, that the real combustion of the body occurs. It occurs in all parts, but most notably in the muscles and the glands. We may figure it as a simple process, and its principles and essential conditions are simple, but it is really very complicated. As we have already seen, this combustion occurs *in water*, and not very hot water at that; and though the business of breathing exists in order to expose the body to an endless and continuous draught, bringing oxygen and removing carbonic acid and water, the actual details of the combustion are far more complicated than our present knowledge can follow.

It is enough, for the present, to note that an isolated muscle, no longer fed with blood, can contract for some time in an atmosphere of pure nitrogen, so that it is getting oxygen from nowhere, and can yet give off carbonic acid, which is a compound of carbon and oxygen.

This means, of course, as we must never forget, that the breathing of protoplasm is vital and internal, that its oxidation is *intra-molecular*. It is for this intra-molecular oxidation of the living protoplasm of our bodies and for the removal of its products that we breathe, since the body of man is a living animal. But we must hurry on, for though it mightily concerns him, this is not yet Man.

ELUSIVE PROBLEMS OF SLEEP

How the Dangers of Insomnia May be Incurred and How They May be Overcome

THE EVIL EFFECTS OF THE DRUG HABIT

UNLESS we have already forgotten our first principles we cannot promise sound sleep for all, by whatever device. We all vary, and some are born to sleep well, and others to sleep badly. Yet there remains a wide field of folly and wisdom in this matter, which each may cultivate as he will, with appropriate results.

Insomnia is bound to be a disease of an age which uses the upper areas of the brain, those most concerned in sleep, more than they were ever used before; an age which eats liberally, not least at night; is huddled together in cities, taking little natural exercise; has lately begun to fill those cities with all manner of unprecedented noises, ranging from the surface cars, through the indescribable streets, to the elevated overhead. Civilization is built upon control, and any high civilization is built upon self-control. It need only be remembered that the man who has not slept is irritable, nervous, not master of himself, for us to realize that the quality of sleep obtained by its units may be momentous for the destiny of a civilization.

Yet here is something which, like everything else, has its causes, and those causes are, on the whole, understood. Sleep and insomnia are very complicated phenomena, and the causes of insomnia are accordingly numerous. Further, our problem lies at, so to speak, the very junction of mind and body; and thus the cause of insomnia may equally well be an undigested supper, a noble strain of music, or a secret sorrow, and its relief may be found in a drug or a bath or the sound of a dear voice. Nevertheless, sleep and lack of sleep can be controlled, in ourselves and others.

The facts revealed and analyzed by modern hypnotism consort exactly with common experience. The factor of suggestion is cardinal in sleep. It plays a part in all our lives, and how can it fail to be conspicuous here? For the good sleeper and the hard worker the question does not arise, but for the rest of us it is all-important. We expect to sleep, and usually we do. We have confidence or "self-confidence," which is none other, obviously, than a form of "self-suggestion" or "auto-suggestion". Or the room is strange, and we have persuaded ourselves that we can never sleep the first night in a strange bed, and so we do not. Now that is the opposite of self-confidence, and the modern psychologists have their own name for that also. They rightly call it "contra-suggestion" — that is, contrary or against suggestion.

This contra-suggestion in the matter of sleep is one of the curses of the modern world, and is well entitled to be placed in the forefront of the present argument. People who suffer from insomnia may remove every other factor of disturbance. They modify their diet, and get the digestion right; they take exercise and massage, avoid excitement and stimulant beverages like coffee, and sedulously devote the whole of their day, the whole of their thought and intention, to the problem of getting to sleep at night, and they fail. The truth is that everything they have done during the day in order to sleep has fed contra-suggestion. If, however, the spell be reversed, all goes well. If the patient believes, if he or she accompanies a friend who positively asserts that the treatment cannot fail, it does not fail.

The smallness of the part played by pain in cases of sleeplessness

The practical moral of all this, which is of such obvious scientific interest, is that we must be sensible and hopeful about our sleep, when there is any reason to think about it at all. We really can sleep if we will only believe it.

Pain is another matter. Here we are not dealing at all with the problem of pain, for that is a thing apart, and requires the appropriate treatment according to its cause. If the pain cannot be removed or relieved by any other means, then only powerful hypnotics will produce sleep, and such cases are only for the responsible doctor, directing them from hour to hour.

It may be added, however, that the familiar pain called "headache" does not count in this connection. There is headache due to local disease within the skull, and that interferes with sleep; but according to Sir William Gowers, a great authority on the subject, it is only headache due to such causes that prevents sleep, and his dictum excludes every headache but one in millions. This means that no one has any right to take, or to advise, or to administer any kind of drug for the relief of ordinary headache in order to obtain sleep.

Rest in bed, and not drugs, the natural cure for headache

After all, it is the experience of every body that we can take a headache to bed and sleep. The mere going to bed is treatment for the headache — rational and scientific treatment, because it removes the cause, as a rule. Going to bed means a slower rate of circulation for the blood, and almost complete rest for the higher centers of the brain. It means rest of the very probably overstrained eyes; it means a more even distribution of the blood within the body, and it discharges the brain from the duties of balancing and so forth which it has performed all day. The simple consequence is that the headache does not keep us awake, for it is being well and accurately treated by going to bed, and soon disappears

We must at once definitely condemn the use of any anodyne drug for the relief of headache on the ground that one wants to sleep. The drugs most commonly abused for this purpose are acetanilid or antifebrin, phenazone or antipyrin, exalgin, antikamnia, and their allies — coal-tar products made with great chemical skill, but entirely unsuited for administration to human beings except under expert supervision.

We have seen that the mental machine is sometimes apt to go on running when we want it to stop, just as it neglects to run freely for some time after we want it to. These are examples of the brain's sensitivity, and should not surprise us. But emotion and excitement are far more important in this connection than pure work as such. Pleasurable emotion often keeps people awake — notably nervous, sensitive and clever children who take their pleasures keenly.

Wise parents and guardians give such children plenty of time to settle down before bedtime, and keep their parties and excitements to sensible early hours. But any harm done them by failure to observe this is nothing compared to that to which young girls are subjected in a New York or London social season, for instance — girls palpably immature, and needing all the special care which adolescence demands, but thrust instead into an atmosphere of excitement and noise and sex and stimulating food and drink at late hours, all of which combine to spoil sleep, vitiate development, and prejudice, perhaps beyond recall, the chances of noble and complete womanhood in the future.

If pleasurable emotion may injure sleep, vastly worse is distressful emotion, especially of the kind which we call worry. Most of the disastrous work done by worry upon mind and body uses insomnia as its instrument. There are emotions which discharge their energy, and, though they are costly, the expenditure pays. But worry is literally "strangling." The choked emotion, without outlet, works havoc within the nervous system which produced it, and only too often wrecks this incomparable machine.

The untimely activity of the mind caused by emotion or worry

Above all, it does so by the simple but supremely effective method of preventing sleep. The patient may eat and drink as he did — not less; but if the nervous system cannot get the essential condition of its nourishment, which is sleep, none other will avail it, and all disasters are possible.

There is a sleeplessness which is patient and resigned, and not restless. Many people who have to bear insomnia do so with wisdom, which enables much of the nervous system to sleep even when consciousness is not abolished. But the insomnia of the worried man is impatient, unresigned and tossing, and that is the kind that kills — sometimes the body, oftenest the mind. Insomnia due to emotion, and, above all, to that we call worry, can safely be controlled only by removing its cause. The narcotics in general have no field of usefulness in this connection, whether alcohol, opium or morphine, chloral, chloralamide, paraldehyde, sulphonal, trional, tetronal, "nepenthe" or even veronal.

The appalling failure of the use of drugs for insomnia

Insomnia is never more terrible than when it leads to disaster by means of drugs. Too often the patient now loses his power of resistance to any narcotic. The drug may not be alcohol, but may just as well be any of those we have named, and more besides. One and all, these are essentially narcotic drugs, though most of them appear to have an initial stimulant action, which is really not stimulation, but the consequence of narcosis of the highest, most susceptible, controlling, checking areas of the brain. The poor fellow cannot sleep, and he welcomes the drugs which narcotize his emotional centers and induce sleep. Too often there are none to tell him, in time, that the end thereof is death; too often the venal adviser is at hand who commends such things, with their immediate and obvious success — and their ghastly ultimate failure.

To refrain from worrying about not sleeping is often the way to sleep

One last point on this matter of worry and sleep, before we turn to the physical aspects of insomnia. Our advice is specially applicable to elderly people, but it is relevant to all cases. It is that if one cannot sleep, knowing by experience, for instance, that, waking up in the morning unduly early, there is no hope of more sleep, it is better not to attempt the impossible. In any case, sleep seldom yields to direct assault and battery. Further, to worry about lack of sleep, to toss and turn and try, and toss and turn and try again, is to remove oneself so much further from the state of rest which is desired It is better to cultivate a little philosophy. If one cannot sleep and must do something, by all means one should read. It costs you far less in life and emotion frankly to give it up, and read at your ease, than to knock your head against the stone wall of your pillow. Better still, but much more difficult, is the practice, possible to some few sensible and self-controlled people, of lying quietly in bed. If a man, lying awake in bed, has muscular rest, sensory rest, and emotional rest, he is perhaps not very far from profiting as much as if he were asleep altogether.

The bunch of nerves behind the stomach that resents pressure

Of equal rank with worry as a psychical cause of insomnia is dyspepsia as a physical cause — pain being excluded from our present consideration. Anyone who is a bad sleeper, or who strikes a spell of bad sleeping, should suspect indigestion in the absence of any other obvious cause, for this is by far the commonest. The same disturbance which produces nightmare may just as well interfere with sleep altogether.

Behind the stomach there lies a great mass of nervous tissue, called the "solar plexus," or "abdominal brain". It is this which disturbs us when we are hit "in the wind". An uneasy stomach troubles the solar plexus and makes an uneasy head producing either nightmare or insomnia.

All the more likely is this to happen if we adopt the bad practice of sleeping on the back, instead of on one side, for the pressure of the stomach, loaded, or in motion, or both, upon the solar plexus is obviously greater when we lie on the back. We may be quite unaware that we have dyspepsia, for the only symptoms may be our poor sleep, and perhaps a coated tongue in the morning. It is quite a mistake to suppose that dyspepsia involves pain, for there are many forms of chronic "atonic" dyspepsia, due to lack of tone in the walls of the stomach, which involve no pain, but are quite sufficient to impair sleep, and therefore to prejudice the general health.

The treatment of all such insomnia is to remove the cause. To take hypnotics, weak or powerful, which have a way of sending the digestion to sleep when it should be active, and which do not touch the cause at all, is folly, and involves the price of folly. The chances are that we may require the skill of a doctor in such cases, but we can also do a good deal for ourselves. It is most probable we require less food. The first need for nine sleepless people out of ten is to eat less at night.

Stimulating beverages which the sleepless should carefully avoid

There should be at least several hours between anything like a heavy meal and the time of sleep. In the course of this interval the stomach should have distributed its contents, or nearly all of them, to the small intestine and bowel, and then one may expect to sleep with a stomach which is empty and resting.

Everyone should know, what experience has taught many, that true cerebral stimulants like coffee and tea should be avoided in the latter part of the day by those whose sleep is precarious. Cocoa need scarcely be feared, though it belongs to the same category, but coffee and tea contain a powerful principle, belonging to the group called alkaloids, which is known as caffeine or theine (they are two names for the same thing), and which directly causes wakefulness, and has no ultimate hypnotic action, like other so-called stimulants.

Coffee also contains a volatile oil which upsets the digestion of some people, and attacks their sleep in that fashion; such people may be able to drink tea with impunity, but cannot sleep after coffee.

In order to sleep, we require the least possible disturbance of the brain by stimuli, either from within or without. Worry and dyspepsia offer contrasted examples of stimuli arising from within, and jogging the brain when it wants to rest. Touch sensations from without often suffice to keep us awake.

How touch sensations and unduly stimulated sight may drive sleep away

The feet must be warm, the skin must be warm, but not too warm. When we are too hot in bed, the flushed skin becomes over-sensitive, and sensations derived from it keep us awake. We may turn back some of the bedclothes, and catch cold. A better plan is to get up and sponge the face, and even the whole body, with cold water, and then lightly dry the skin and return to bed. The removal of perspiration removes the cause of irritation, and very often the getting up and the temporary cold offer a hint to the brain-center which controls the distribution of blood.

Morning insomnia due to the break of day is a kind of absurdity when coupled with the fact that we stayed up with artificial light for some hours the night before. Failing any change in general practice, or even the adoption of a radical daylight saving law, we have to accept the situation; and many poor sleepers can get relief by using dark green shades for their bedroom windows. Most dreams are visual, and their visual character shows that the brain-centers connected with vision have been unduly stimulated before sleep, and so made specially sensitive when the solar plexus, for instance, sends up irritating messages to the brain.

Probably this congested or excitable state of the brain-centers of vision is due not only to reading and writing, but also to the too brilliant lighting of our living-rooms at night, especially since artificial light can never have the same hygienic qualities as natural light.

The noises of cities as spoilers of sleep and promoters of dreams of hearing

Sensations of sound are equally undesirable during sleep; and so is excessive stimulation of the hearing centers before it. Many people thus have to beware of music late at night. There is such a thing as ear-strain, and, unfortunately, we have no earlids. The noise of cities is disastrous in persuading people to close their bedroom windows; and also in spoiling sleep and inducing dreams of hearing, which are said to be becoming as common as dreams of vision, in consequence of the increasing ear-strain of the present day. Hospital authorities agree that the number of people with nerve weakness who suffer specially from "irritable weakness" of the ears, rather than the eyes, is increasing.

Wanted: a crusade against noises that are unnecessary, or unnecessarily loud

The only practical suggestions that can be made here are two: first, that we should join in the formation of public opinion against unnecessary noise, especially at night; and second, that, instead of the dangerous practice of closing the bedroom window, we should employ cotton-wool or other ear-plugs, which are safe, effective and convenient. As regards the former point, physical and physiological experiment prove that sounds of low pitch have relatively short range. All noises purposely made by automobiles ought to be of low pitch, being then perfectly effective at the short range which is alone required. The high-pitched notes and the new noises that are not notes should be forbidden by law, whether by night or by day.

Those who like warm baths should take them at night. They must not be so hot as to leave the skin irritable; but short of that they soothe, and are definitely sedative, in the main, probably because they withdraw blood from the brain. Nor is this the only way in which the skin may be employed for purposes of sleep. The soothing effect of gentle stroking, say of the forehead, is felt by many people; and this is utilized in massage for insomnia, often a most useful and effective remedy.

Hypnotism and rest-cure isolation as hopeful remedies for insomnia

A person suffering from neurasthenia or nerve-weakness, and unable to sleep, is usually debarred from much or any exercise, for the nerves will not stand the work involved; and that, in itself, makes sleep more difficult.

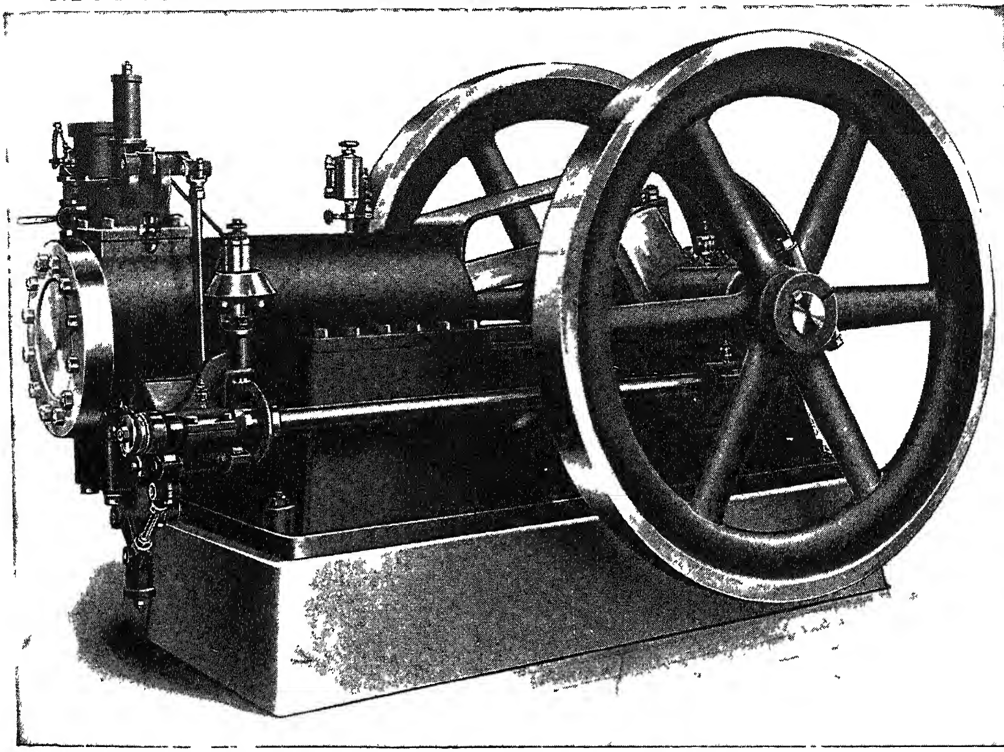
Here the warm bath at night and skilful massage, may be invaluable. The massage gives the muscles a kind of exercise without calling upon the resources of the nerves. But it is important that the massage be not irritating to the patient.

Hypnotism has proved itself, as we have already noted in passing, a valuable and safe remedy in many cases of chronic insomnia. The treatment may require to be repeated at intervals of a few months, especially with hysterical patients — who, as a rule, are easily hypnotized. Neurasthenic patients, on the other hand, are usually refractory subjects; and, of course, if the patient will not go under, the remedy is not available. But it is a distinct item in the armory of modern medicine against insomnia, and many have reason to be grateful to the French pioneers.

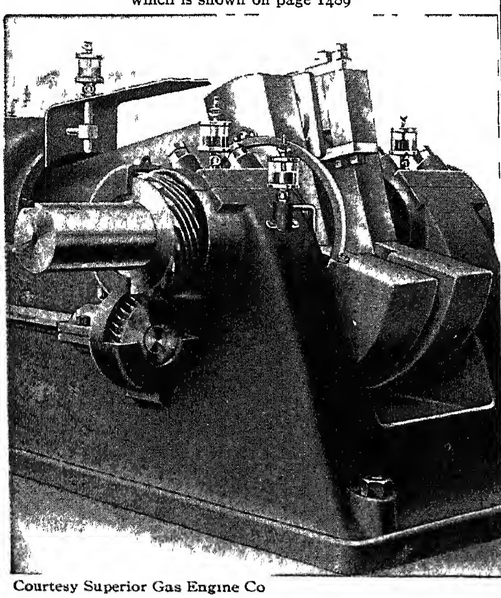
The "rest-cure" in its original form, as introduced by our famous American physician, and called, after him, the "Weir-Mitchell treatment" was advocated for insomnia. Its essentials were isolation, massage, and over-feeding, but the latter item was much modified when insomnia was the essential trouble. The isolation was considered most important in breaking an insomnia that threatened to be dangerous and yielded to nothing else.

We know today that many of the causes of insomnia may be quite deep-seated. When one is losing sleep due to worry, for example, it may very well be due to complex psychic disturbances. The teachings of Sigmund Freud and the whole school of modern psychiatry stress the fact that many seemingly simple physical disturbances, such as upset stomach, headaches and sleeplessness may very well be non-organic in nature and psychic in origin. Doctors have even discovered that skin diseases may sometimes be due to mental causes.

MODERN GAS ENGINE OF MODERATE SIZE



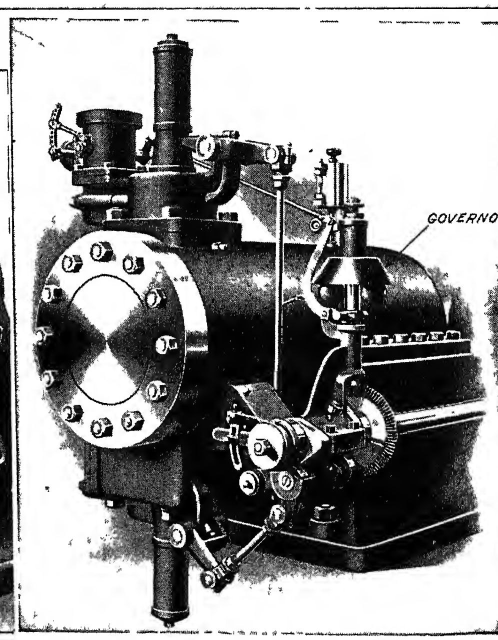
The auxiliary shaft which operates the valves is seen on the side of the engine, sectional view of which is shown on page 1489



Courtesy Superior Gas Engine Co

CRANK-SHAFT END OF ENGINE

Showing the gearing which drives the auxiliary shaft that operates the valves.



CYLINDER-HEAD END OF ENGINE

Showing the valve mechanism operated by the shaft and gearing, and the governor.

POWER FROM GAS

The Marvels of the Transformation of Waste Products into Useful Workers

HOW GAS PRODUCERS AND GAS ENGINES OPERATE

OUR greatest source of power to-day is heat, and the most available source of heat is the combustion of fuel. Fuels are of many kinds and are either solid, liquid or gaseous. Power is obtained from fuel by using the heat of combustion to expand some medium like steam, air or gas, thereby moving the working parts of some kind of heat engine. Heat engines are divided into two general classes, depending upon the manner in which the fuel is burned. In the first class the combustion takes place *outside* of the engine, the heat being transmitted through its walls to the working medium. Engines of this class are called "external-combustion" engines. The best known example is the steam engine, while another, less well known, is the hot-air engine which uses air as a working medium. In heat engines of the second class the combustion takes place *inside* of the engine and the products of combustion usually act directly upon its working parts. Such engines are known, therefore, as "internal-combustion" engines and are well illustrated by the ordinary gas and oil engines. Obviously the external-combustion engine can utilize solid, liquid or gaseous fuels, while the internal-combustion engine can make direct use only of gaseous fuels or of such liquid fuels as can be easily volatilized; and it is only by first converting them into gaseous form that it can indirectly make use of solid fuels.

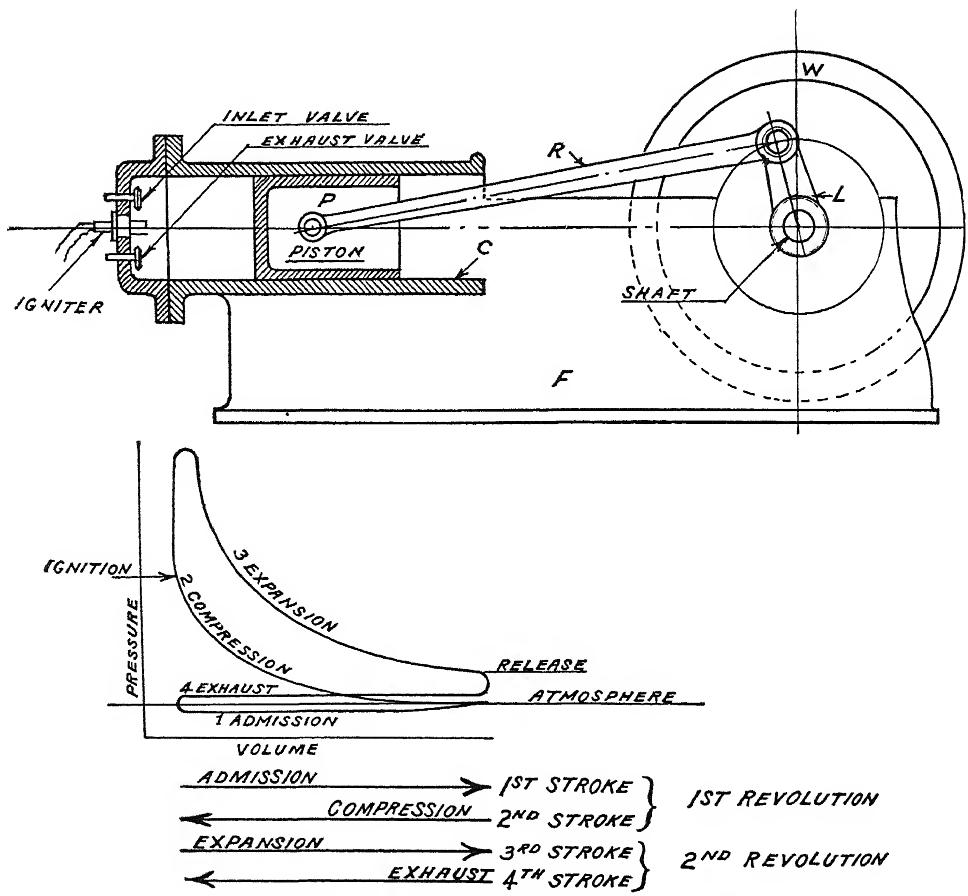
But while the external-combustion engine can utilize a wide range of fuels, its efficiency is lessened because of the losses inherent in its method of applying the heat to the working medium.

The best steam plant cannot convert over 16 per cent of the heat of combustion into useful work and an average plant will only convert from 6 to 10 per cent. Such a plant consists, too, not only of boilers and engines, but includes a large number of auxiliary appliances, such as pumps, condensers, economizers, etc., which make it somewhat complicated. A considerable amount of fuel is required to raise steam when starting up, and, if the plant is to be in a state of readiness, to keep up steam even when the engines are not running. Considerations of this kind long ago induced engineers to seek a more direct method of applying heat to the production of power. The modern gas and oil engines are the result of this effort. The best type of internal-combustion engine can convert 35 per cent of the heat of combustion into useful work, while ordinary gas engines can convert from 15 to 20 per cent. As will be seen, the ordinary gas engine plant is much simpler in construction as well as in operation than the steam plant, although larger plants do not always possess a marked superiority in these particulars.

There is no marked difference between internal-combustion engines using gas as fuel and those using gasoline or other liquids that can be readily volatilized into gas. Theoretically and structurally such engines are alike, but those using liquids, such as gasoline, must be equipped with a carburetor or some similar device for volatilizing the liquid on its way to the working cylinder. In engines using crude oil or heavy distillates of crude oil directly in the working cylinder the cycle

of operations is somewhat different from the ordinary gas or gasoline engine, and the auxiliary appliances for feeding the oil are much more complex than anything connected with the ordinary gas engine These more complex forms of internal-combustion engine will be more easily understood after a discussion of the simple gas engine. This chapter, therefore, will discuss engines that use gaseous fuel only, and consideration of engines that burn fluid fuel will be found in a succeeding chapter.

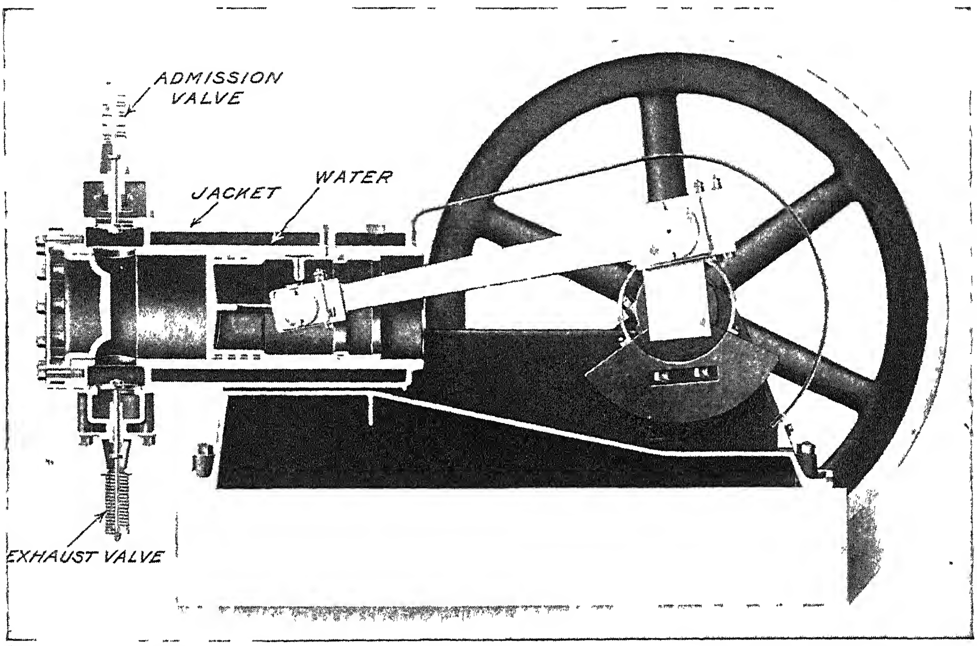
Of the many types of gas engine that have been invented only those based on the cycle of operations patented by the French engineer Beau de Rochas in 1862 have survived. This principle was not embodied in an actual engine until 1878 when Dr. Otto, a German, brought out his gas engine, reinventing the Beau de Rochas cycle and applying it practically. The Otto cycle will be made clear by studying the accompanying diagrammatic illustration of a cross section of a gas engine. In the diagram, C is the cylinder in which the piston P moves backward and forward. The connecting rod R connects the piston with the crank L, so that the crank is made to turn as the piston moves to and fro. W is the fly-wheel which equalizes the energy released by the explosions in the cylinder. The cylinder and crank-shaft are held in permanent relation by the frame F. The inlet valve is connected to the gas and air supply and the exhaust valve to the air, or to a muffler to deaden the noise of exhaust. An electric spark is generated by the igniter for the purpose of exploding the



DIAGRAMMATIC EXPLANATION OF FOUR-CYCLE GAS ENGINE

charge of gas and air, the time of ignition being controlled by a timing device driven from the mechanism which operates the inlet and exhaust valves. The pressure in the cylinder at every stage of the cycle is shown by the "indicator card" which accompanies the diagram.

Consider the piston to be at its extreme inward position with reference to the cylinder and to be starting outward. As it moves forward it creates a slight vacuum in the cylinder behind it, and, as the inlet valve is open, air and gas in definite proportions rush into the cylinder throughout the entire stroke. On the inward or second stroke the inlet valve is closed and the air and gas are compressed until the stroke is nearly completed, when ignition takes place. The mixture of gas and air burns so rapidly as to create an explosion causing a pressure of from two to three hundred pounds to the square inch, which forces the piston to return on the second forward stroke, the hot gases expanding and the pressure falling. The exhaust valve opens when the piston is near the end of this stroke and during the second inward stroke the burnt gases are expelled. The pressure in the cylinder during this expulsion stroke is necessarily a little above that of the atmosphere. This completes the cycle, and in the next outward stroke a fresh charge is drawn in. It will be noted that energy is supplied to the piston on only one of the four strokes, the fly-wheel equalizing this energy over the remaining strokes and by so doing keeping the revolutions of the crank-shaft from markedly varying from the required normal. Gas engines operating on the Otto cycle are commonly known as "four-cycle" engines from the fact that there are four piston strokes to every power cycle.

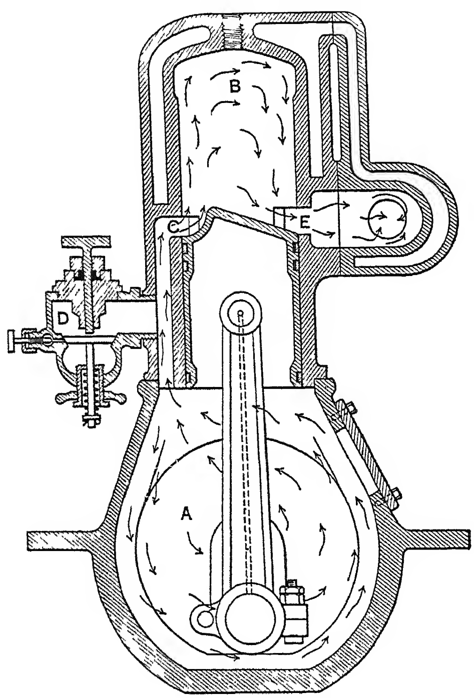


Courtesy Superior Gas Engine Co
SECTIONAL VIEW OF MODERN GAS ENGINE OF FROM 20 TO 100 H. P. ILLUSTRATED ON PAGE 1486

The accompanying illustration of a modern gas engine of twenty to one hundred horse-power in cross section shows the valves as they actually appear and the outer cylinder or jacket that surrounds the main working cylinder. Water is circulated in the space between the outer and inner cylinders in order to keep the latter cool under the tremendous heat generated which otherwise would soon destroy the working parts. A large share of the heat of combustion is thus carried away and this constitutes the greatest loss of potential power in the gas engine. The mechanism for opening and closing the

valves and for timing the spark is operated by a small shaft parallel to the engine, driven off the main shaft at one-half the speed of the latter, so that the valves open and close once in every two revolutions as required by the cycle of operations. The charge is ignited by a spark produced by breaking an electric circuit, the mechanism for which is sometimes inside, but more usually outside, the cylinder head.

It will be clear that the same engine could be made to deliver more power if it could receive an explosive impulse every

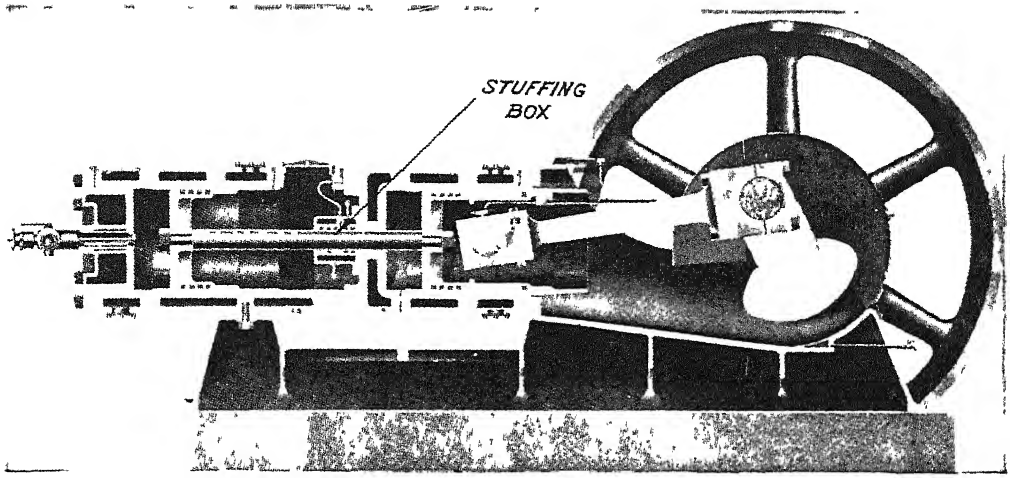


CROSS SECTION OF A TWO-CYCLE CAILLE GAS ENGINE

revolution. This can be accomplished, of course, by closing the outer end of the cylinder and using a rod to connect the piston with an outside crosshead, as in the steam engine. This is done in some large engines, but it then becomes necessary to water-jacket the piston and rod, which is expensive and complex. Many efforts have been made to accomplish the same result and still leave the outer end of the cylinder open to the air. One of the methods by means of which this has been done is illustrated by the cross-sectional view of the Caille engine which is shown above.

In this illustration *A* is the crank case and is closed so that air cannot enter except through the supply chamber *D*. A port *C* connects this chamber with the cylinder *B*. The piston is shown in its lowest position. As it moves upward it closes the port *C* and creates a partial vacuum in the crank case. This causes the valve at *D* to open and admit gas and air to the crank case in proper proportion. When the piston reaches its upper position the charge which it compressed in its upper movement is exploded, starting the piston downward. As the piston moves downward the valve at *D* is closed and the air and gas in the lower case are compressed to four or five pounds to the square inch. The piston in descending first opens the exhaust port *E* and allows the burnt gases to escape. Shortly afterward it opens the port *C* and permits the gas and air in the crank case to flow into the cylinder, driving out the burnt gases that remain. The piston on its next upward stroke closes the ports *C* and *E*, compresses the charge, and the cycle is then repeated. There is thus an explosion every revolution of the crank or one for every two strokes of the piston. This form of engine therefore is commonly known as a "two-cycle" engine. While it gives more power for a given cylinder than the four-cycle machine, it is not so efficient. Unless the proportions are exactly right, gas will escape into the exhaust without being exploded. On slow speeds the hot gases sometimes flash back and explode the charge in the crank case. While this is not particularly dangerous, it interferes with the operation of the engine at low speeds. The two-cycle engine is much simpler in construction than the four-cycle engine, and for this reason has proved very convenient for small motor boats, where high efficiency is not a deciding factor.

Another method of obtaining an explosion for every revolution of the shaft without closing both ends of the cylinder is accomplished by arranging two four-cycle engines in tandem, with the timer so set that first one cylinder and then the other receives an impulse as the piston starts forward. Thus while each piston



ALBERGER TANDEM FOUR-CYCLE GAS ENGINE WITH TWO CYLINDERS
The two cylinders receive a power impulse alternately, thus giving a working stroke every revolution

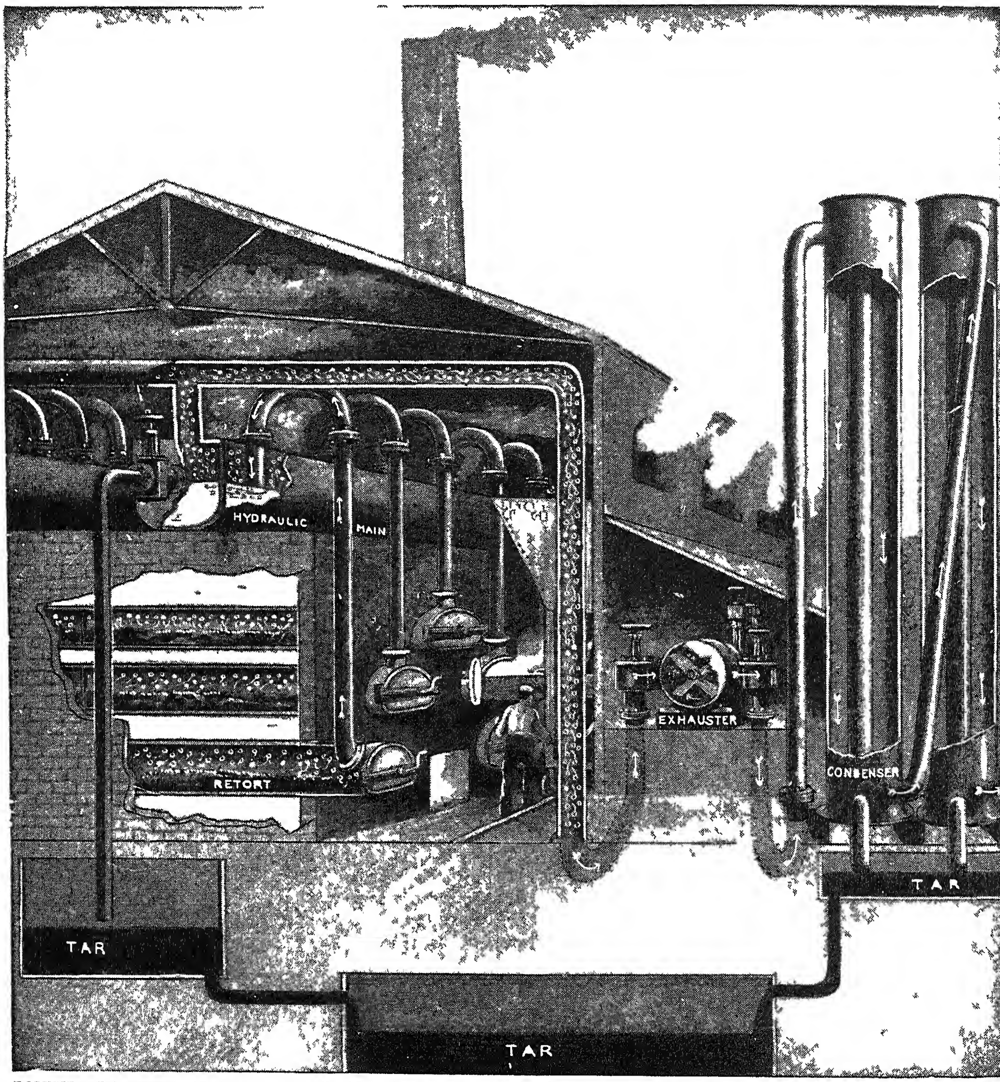
receives an impulse every other revolution the combination receives one every revolution. Both the two-cycle and the tandem engine just described will run somewhat steadier than the four-cycle.

There are several kinds of gas, principally made up of carbon, hydrogen and oxygen and their compounds, diluted more or less with nitrogen, that can be used successfully in gas engines. Natural gas is an excellent fuel, but it occurs only in a few limited areas and its production is somewhat uncertain.

The illuminating gas used in cities is also a good fuel, but expensive. It is made by two methods. In the first, bituminous coal is heated in an air-tight retort so that no combustion can occur. The heat drives off the hydrocarbon gases in the coal leaving what is known as "coke" in the retort. The gas as it leaves the retort carries with it undesirable impurities. Some of these are removed by cooling the gas and condensing them (like tar), while others (like dust) are removed by passing the gas through scrubbers, where it is exposed to a fine spray of water, and by other purifying processes. The second method produces "water gas", so-called, by blowing steam through a bed of incandescent anthracite coal thereby breaking up the steam into its constituents, hydrogen and oxygen. The oxygen combines with the carbon of the fuel and forms carbon monoxide CO, which is a combustible gas. The water gas as it leaves the retort requires enrichment before it can be used for illuminating purposes, and this is accomplished by adding hydrocarbon vapors obtained by heating crude oil or some of its products.

In the making of coke in coke ovens for commercial purposes by-products of tar, ammonia and gas are produced. Coke-oven gas does not differ materially from illuminating gas and can be used in gas engines. Oil gas is made by mixing the vapor of crude oil or its products with steam and heating the mixture in a retort to 600° F., thus producing a gas that is rich in hydrogen In smelting iron ores a vast amount of combustible gas is produced that formerly was entirely wasted. It is estimated that at least three-quarters of a million horse-power in Great Britain and three million in this country goes to waste from blast furnaces night and day in this way. The method of recovering these gases and the engines used in burning them will be discussed later on in this chapter.

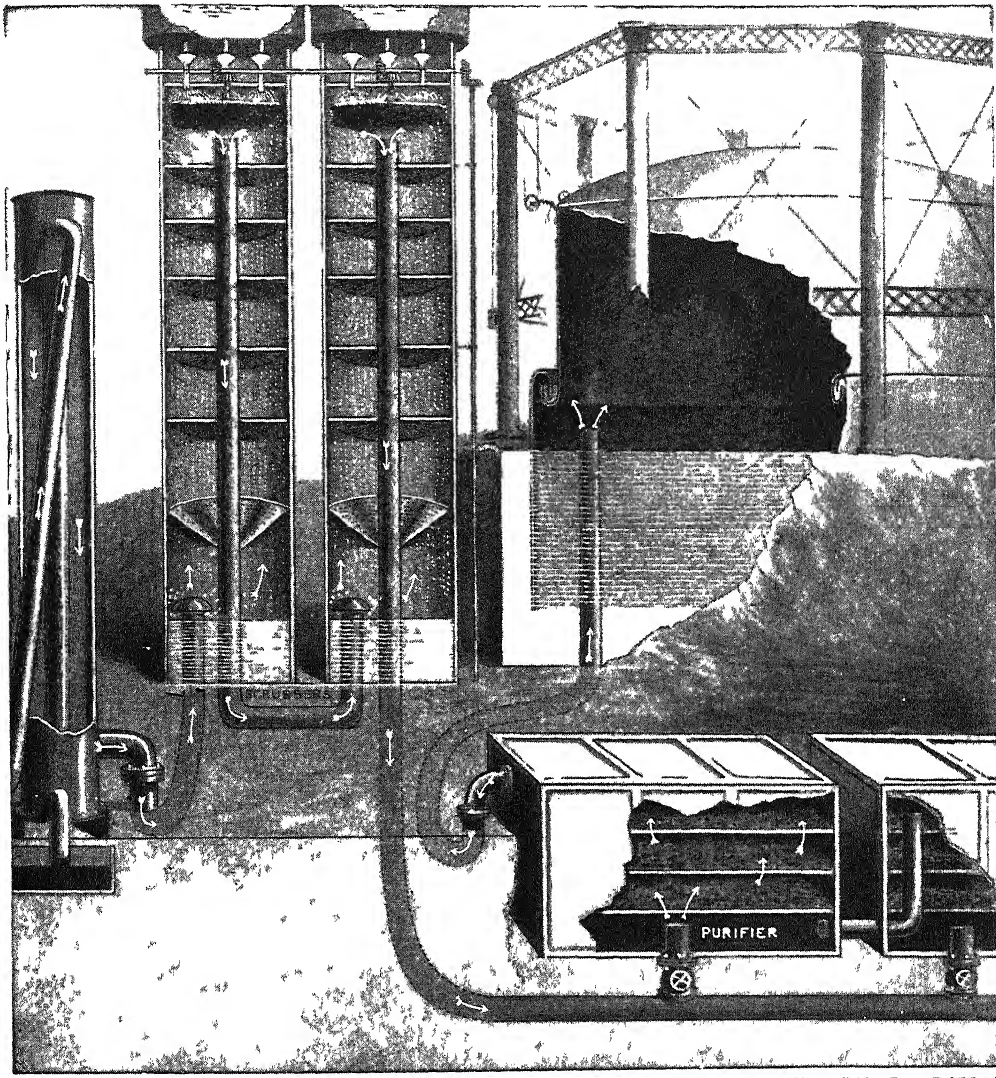
All of the gases described in the foregoing have limitations so far as their use in gas engines is concerned. Illuminating gas is too expensive, coke-oven and blast-furnace gases are limited geographically, and these considerations gave rise to a demand for a method of producing gas for this purpose that would not be subject to these objections. This demand has brought the modern "gas producer", so-



PICTURE-DIAGRAM OF MODERN GASWORKS, SHOWING COURSE FOLLOWED BY THE GAS FROM THE

called, into existence The problem of obtaining gas from solid fuel is an old one and the modern illuminating gas plant, already described, is one result of long experiments looking to its solution Others were directed to securing a cheap and efficient gas for industrial purposes

The first successful industrial gas producer was built by Sir William Siemens in 1861 for metallurgical purposes, and the Siemens producer is still used in such work In it a very thick bed of anthracite coal or coke is fired from the bottom The fuel is fed from the top by a mechanism that excludes the air, so that the only air that can enter comes in at the bottom and under control Only enough air is admitted to burn the fuel just above the grate, the remainder becoming very hot The combustion at the bottom of the fuel bed produces carbon dioxide or, as it is known chemically, CO_2, the symbol signifying that one atom of carbon is combined with two of oxygen Carbon dioxide or carbonic acid gas, as it is sometimes called, will not burn As this gas rises through the hot bed of coal or coke toward the delivery pipe, it takes up more carbon from the upper part of the bed and becomes carbon monoxide, or CO, which is a combustible



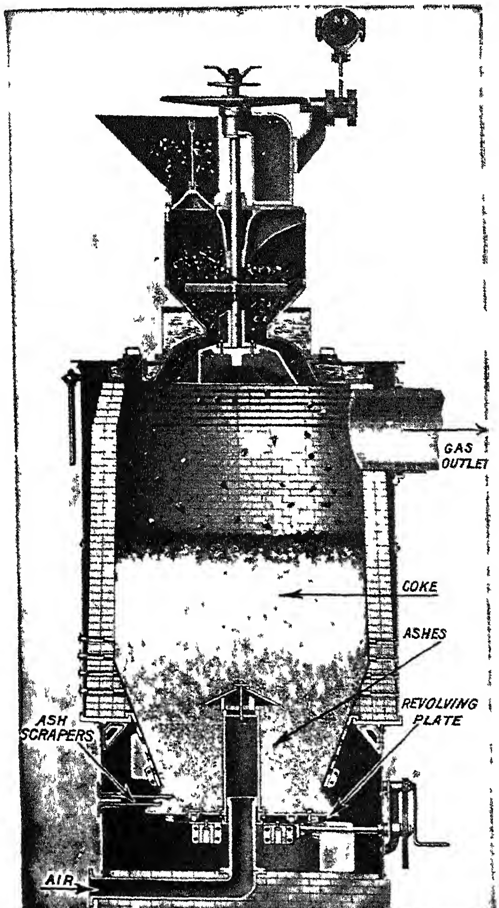
RETORTS THROUGH CONDENSERS TO THE GASOMETER, AND THE COLLECTION OF THE TAR BY PRODUCT

gas The pale blue flames which can be seen playing on top of any heavy bed of burning coal or coke are caused by the combustion of carbon monoxide It is a deadly poisonous gas

The gas from the Siemens producer, while very satisfactory for a wide range of industrial uses, is not suitable for use in gas engines, and it was not until 1878 that J E Dowson, of England, made the first producer plant that generated such It will be remembered that in making illuminating "water gas," so-called, steam is blown through the incandescent fuel bed, thus enriching the gas by the hydrogen and oxygen resulting from the breaking up of the steam into its constituents Dowson's improvement on the Siemens method was to introduce the steam into the bottom of the furnace in the form of a jet, also utilized to induce the inflow of air This process makes a gas somewhat poorer in quality than water gas, but richer than Siemens gas and well suited for use in gas engines It has the great advantage of cheapness, and has made possible the construction of large gas-driven power plants

Dowson's work led to the development of modern gas producers of the so-called

"pressure type," examples of which are shown in the accompanying illustrations. The gas producer proper usually consists of a cylindrical metal shell lined with brick with a device for feeding coal into the top without admitting air. A heavy bed of coal occupies the middle portion of the producer and one of ashes the lower part.



Courtesy R D Wood & Co

A TAYLOR PRESSURE GAS PRODUCER BURNING ANTHRACITE COAL

The blast is introduced through the central tube The removal of the ashes is facilitated by a revolving table at the bottom. The feed is automatic and continuous

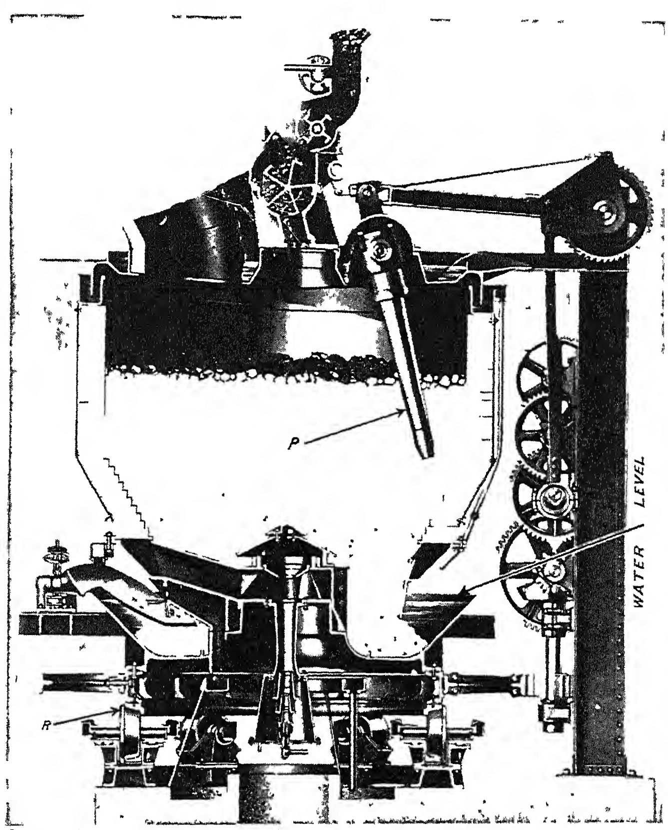
A blast pipe at the bottom admits the air and steam necessary. The ashes drop out of the bottom, a rotating grate being sometimes provided to facilitate their removal. In most producers of this type, however, the lower end rests on a few narrow legs in a pan-shaped depression which is filled with water to a height somewhat above the lower edge of the shell, thus sealing the producer so that air cannot enter and gas cannot escape. The ashes are easily removed by scraping them out of the depression.

In many industrial processes where heat only is necessary, producer gas may be burned as it comes from the producer; in fact in some cases, as in the ceramic industry, the producer and the kiln are built as one structure. If the gas is to be used for power purposes, however, it must first be cleansed of some of its impurities. The gas leaves a pressure producer at a high temperature and is usually conducted first to an "economizer" where it gives up much of its heat to air which is about to be supplied to the producer, or to water which is on its way to the producer to provide steam for the process. From the economizer the gas passes to the "scrubber" where it meets a spray of cold water which cools it still further and takes away the dust and solid impurities. It then goes to the "purifier" where the remaining impurities are removed chemically, or it may be passed through another "dry-scrubber," and thence to a gas holder similar to that used for city illuminating gas. When anthracite or coke is burned in a pressure producer little or no chemical purifying is necessary, but bituminous coals produce tar and other troublesome compounds that must be removed before the gas can be admitted to an engine. Since the entire system operates at a pressure somewhat above atmospheric it is important that there be no leaks in the pipes and apparatus, as the gases produced, while colorless and odorless, are very poisonous.

It will be obvious that if the gas producer is to give a steady supply it must be fed fuel uniformly. For this reason some of the more modern producers have automatic mechanical feeding devices which assure the correct amount of fuel, a great advantage over intermittent hand feeding. The product arising from the fuel bed is a mixture of gases, as has been shown, and in order to secure a steady flow of all the constituents it is advantageous to stir the fuel bed. This is particularly true in burning bituminous coals which

tend to cake up and seal off the passage of the gas from the fuel bed. In some producers the entire fuel bed revolves and as it rotates an oscillating poker stirs it thoroughly, thus keeping it well broken up.

The pressure-producer plant is somewhat complex, but because of the gas holder it has the advantage of being able to respond to extreme variation in the demands for power, without interfering with the working of the producer proper. Pressure producers are employed, therefore, for large installations, especially where bituminous coal is used as fuel. For the greater number of plants, that is those of less than 300 horse-power capacity, the "suction producer" has been found to be more satisfactory. In 1894 M. Benier of Paris conceived the idea of drawing the air and steam through a producer by using the suction stroke of a gas engine, which thus would automatically regulate the amount of gas generated. This idea has been perfected in what is now known as the "suction producer," the general construction of which is somewhat different from the pressure producer. It does not require a water seal, but the device for feeding coal at the top of the producer must exclude the air as in the pressure producer. The gas generated is utilized first in a vaporizer where it gives up its heat to produce the steam which is drawn into the bottom of the producer. Nearly all suction producers are operated with coke or anthracite coal and consequently a single scrubber is usually sufficient to purify the gas. The scrubber is usually a cylindrical chamber filled with coke and fitted with a water spray at the top. The gas rising from the bottom is thus finely divided and thoroughly washed In most cases it then passes directly to the engine.



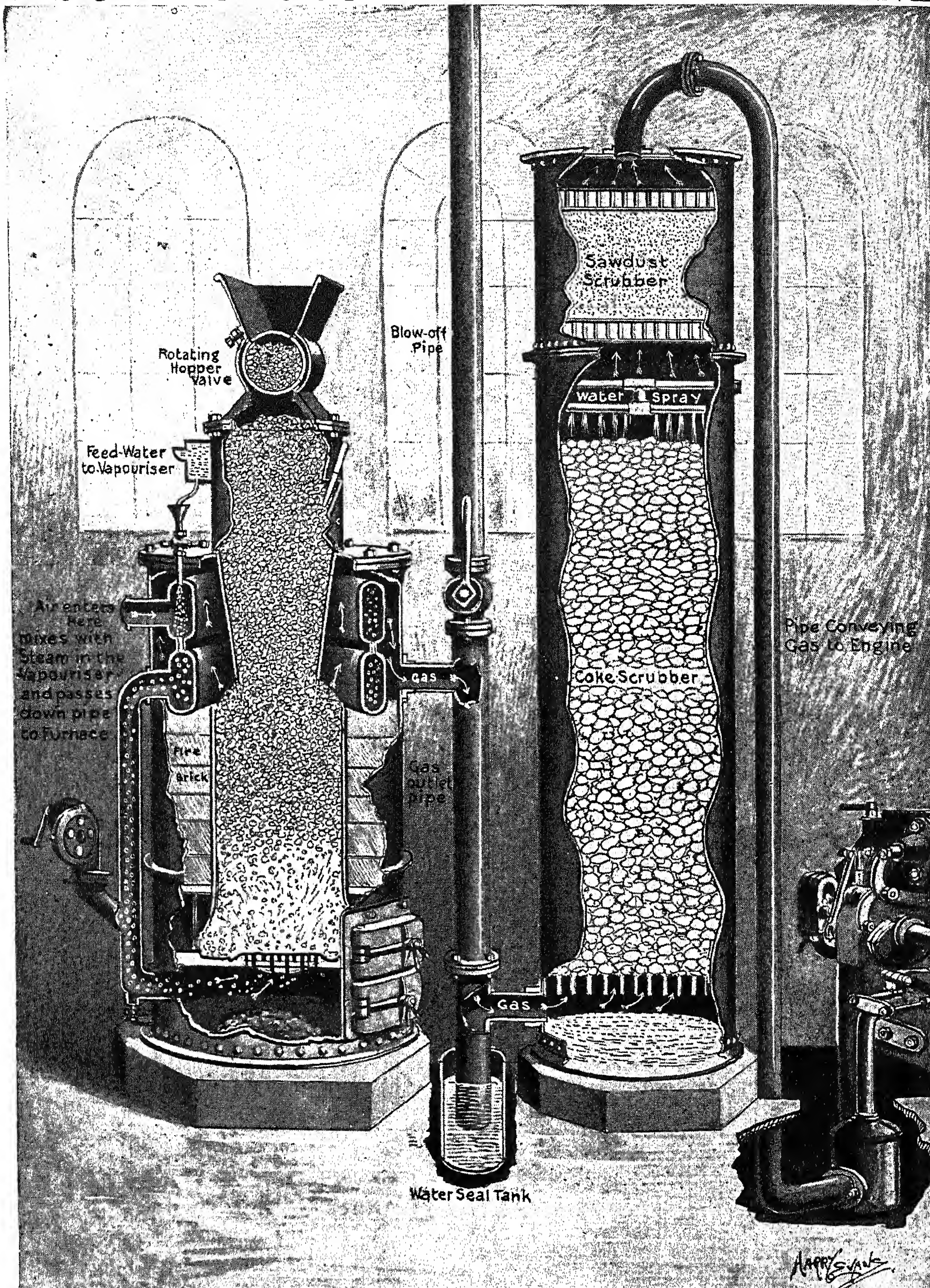
Courtesy Wellman Seaver Morgan Co

WELLMAN MECHANICAL PRESSURE GAS PRODUCER WITH WATER SEAL

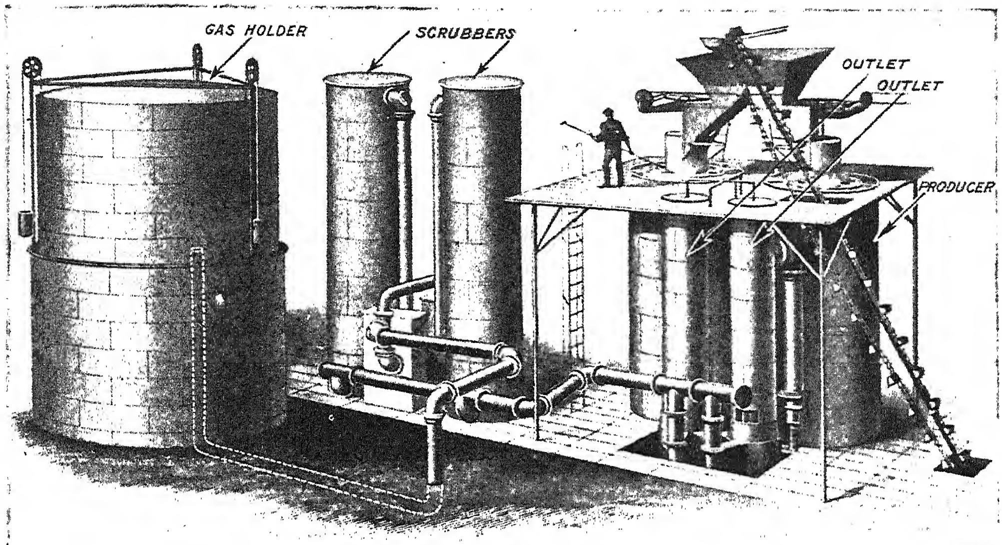
In this producer the body of the machine rotates upon the rollers *R*, while the mechanically operated poker *P*, which is attached to the stationery top, vibrates back and forth, thus constantly stirring the fuel bed

Suction gas producers must be started by auxiliary help. This is usually done by means of a small hand-driven blower, the products of combustion being allowed to go through a by-pass valve directly to the atmosphere until the escaping gas will burn readily; the valve is then closed and the gas turned into the scrubbers, filling the entire plant with gas; when combustible gas appears at a small cock near the engine the latter can be started, the blower stopped, and the functioning of the producer becomes automatic. It is as essential to have all pipes and connections perfectly tight in the suction producer as in the pressure producer, because if air should enter there would be imminent danger of an internal explosion taking place.

ITS OWN GAS SUPPLY FOR A GAS ENGINE



This picture-diagram of a suction gas producer plant shows the method by which a cheap gas for driving an engine is made in an upright iron cylinder and, after passing through a scrubber containing coke and sawdust which cool and clean it, feeds the cylinder of the engine by way of a small reservoir, which regulates the supply.



Courtesy R. D. Wood & Co.

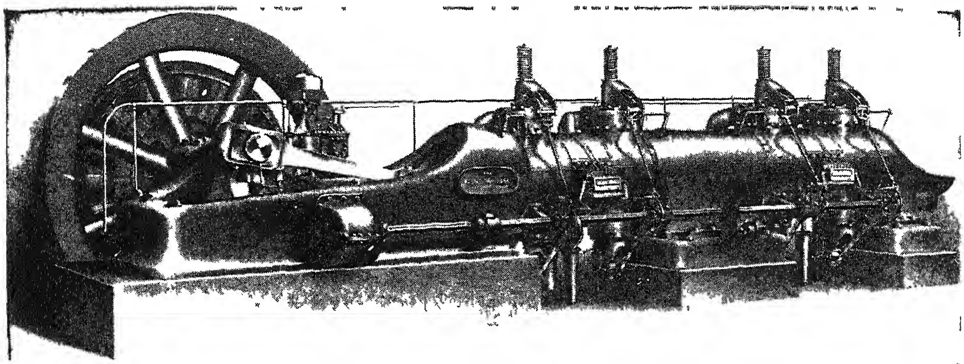
400 H.P. ANTHRACITE GAS POWER PRESSURE PLANT FOR THE ERIE TERMINAL AT JERSEY CITY

The problem of burning bituminous coal in a suction producer is a troublesome one, because of the difficulty in getting rid of the tar and other heavy impurities. These can be removed by scrubbing processes, but a better way has been developed in the "down-draft" producers in which the air is introduced at the top of the fuel bed and drawn downward, the products of combustion passing through the fire. The tar-like products are thus heated to such a temperature as to break them up into permanent gases. Another method is to feed the coal into the bottom of the producer when, the fire being on the top of the fuel bed, the gases on their way upward must pass through the fire.

The compactness and simplicity of the suction producer makes it suitable for use with small engines, and they are manufactured in standard sizes as low as 25 horse-power. They are successfully used in gas-driven launches. Producer gas has the advantage of giving off little smoke, and offers the possibility of utilizing inferior fuels. America has been somewhat behind England and the Continent in the use of gas producers, due probably to the cheapness of coal in this country. In recent years, however, interest in this method of obtaining power has grown rapidly and there are now many large producer plants here, serving a wide range of industry. They cost to install per horse-power as much as or more than the steam engine, but the cost per unit of power produced is less, and, in the matter of reliability of operation and service they compare very favorably with the latter.

In recent years there has been a rapid development of very large gas engines to take advantage of the great quantities of gas that are to be had where natural, blast-furnace or coke-oven gas is available. Single units that develop 5000 horse-power are not uncommon. Blast-furnace and coke-oven gas must, of course, be cleansed of impurities before they can be used and success in operating with them depends to a large degree on the effectiveness with which this is accomplished. Blast-furnace gas is usually carried through a series of cooling towers where it is sprayed with water to remove the dust and impurities. It is also passed through a centrifugal fan in company with water, the action of the fan tending to throw the heavy particles outward and the water collecting and retaining them.

Large gas engines while operating on the same principles as smaller ones possess many unusual features not found in small engines. It has already been shown that a gas engine running on the simple Otto

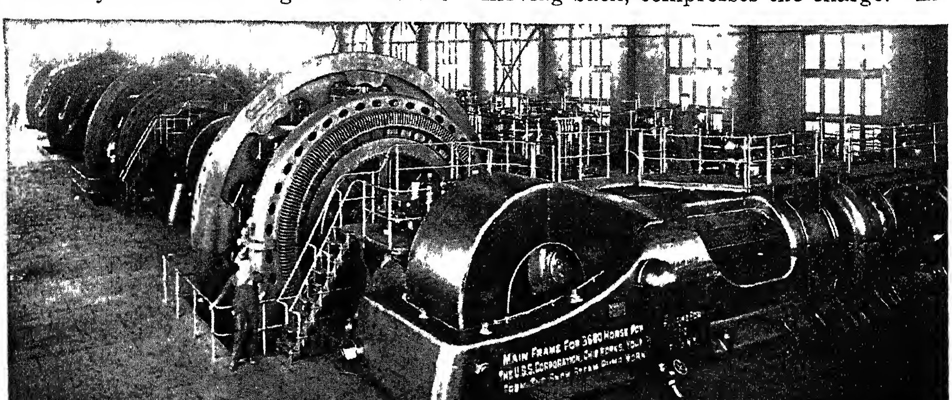


Courtesy Westinghouse Electric & Mfg Co.

TANDEM DOUBLE-ACTING GAS ENGINE DRIVING AN ELECTRIC GENERATOR

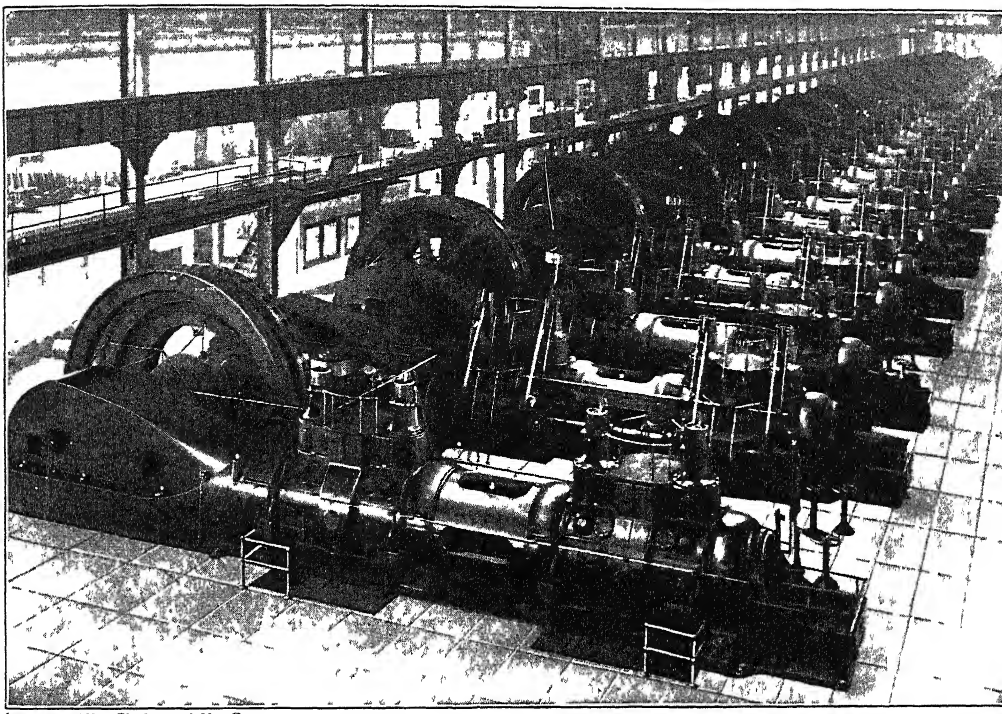
or four-cycle plan receives only one power impulse every four strokes or every two revolutions. While this is satisfactory in small engines, it is not so in larger units. Engines of fairly large size are therefore built with two-tandem cylinders operating on the four-cycle principle, the engine thus receiving an impulse every revolution on the outward stroke In large engines it is customary to use tandem double-acting engines, so that the crank receives an impulse at every forward and every backward stroke. In engines from 2000 horse-power upward it is customary to place a double-acting tandem engine on each end of the crank shaft, thus securing a very steady running machine. Great care must be taken to conduct away some of the heat so that the internal working parts will not be burnt out The cylinder walls, the piston, the piston rod and all other parts subjected to the high heat of the explosion are water-jacketed. As some of these parts are in constant motion, this introduces an expensive construction that can be justified only where there is a decided economic gain in the use of these large units. The accompanying illustrations show the size and complexity of these great machines.

In engines of the Koerting type independent gas and air pumps are used to compress the charge sufficiently to make it flow quickly into the main cylinder As the piston nears the end of the stroke the exhaust valve opens and permits the burnt gases to escape. Shortly after this the air valve opens and air is forced in, sweeping out the remainder of the spent gases As the piston starts back the gas valve opens and the gas compressor forces the charge of gas into the cylinder. It remains open only long enough to do this and the piston, moving back, compresses the charge. Ex-



Courtesy Worthington Pump & Machinery Co

LARGE GAS ENGINES BUILT FOR THE UNITED STATES STEEL CORPORATION



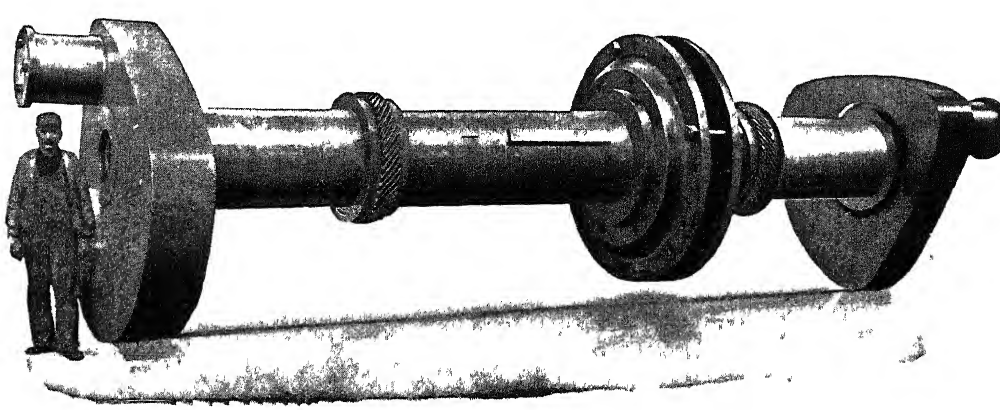
Courtesy Allis-Chalmers Mfg Co

SEVENTEEN TWIN TANDEM BLAST FURNACE GAS ENGINES DIRECT CONNECTED TO 2500-KILOWATT ELECTRIC GENERATORS

Eight blowing engine units with engines similar to these are used in another part of the same plant

plosion takes place at the usual time. In these large engines, however, more than one spark is needed because if the charge were ignited at only one point, the combustion would not extend rapidly enough in the great mass of gas to secure perfect combustion before the crank turns the center and the piston starts forward.

It will be noted that by this arrangement the piston receives an impulse every time it reaches the end of either stroke, as both ends of the cylinder are equipped with auxiliary pumps. Each cylinder of the Koerting type of engine is, therefore, a double-acting, two-cycle machine and produces a large amount of power as compared

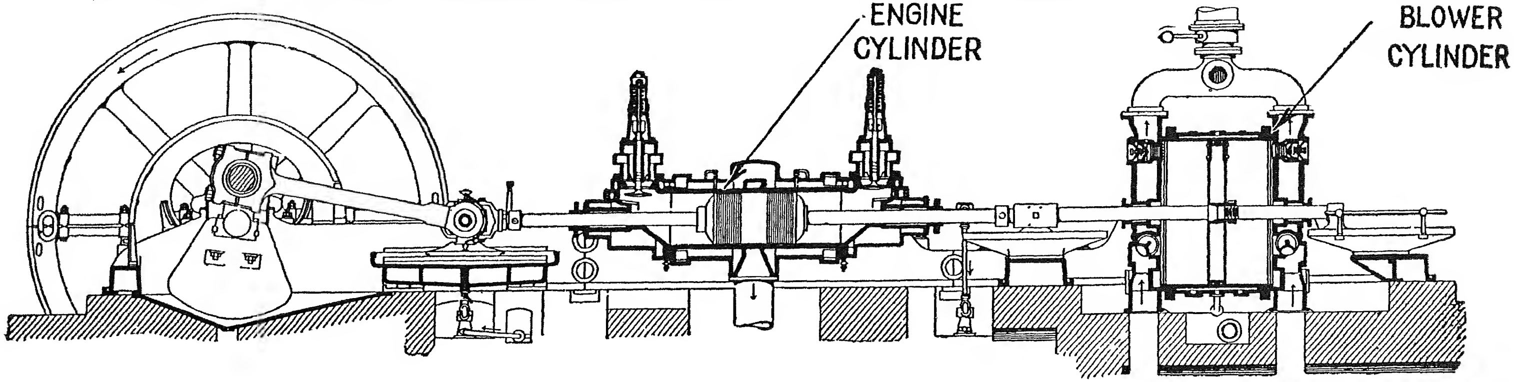


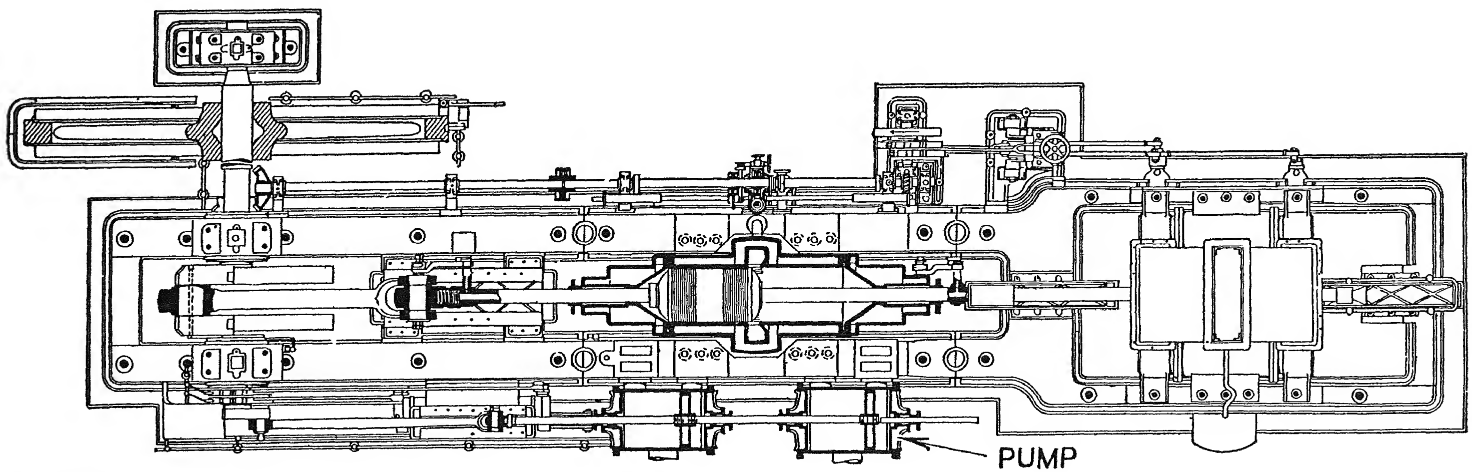
Courtesy Allis-Chalmers Mfg Co.

CRANK SHAFT OF A LARGE GAS ENGINE GENERATING UNIT

Shaft with crank weighs 120,000 pounds. Crank pin (above man's head) is 20 inches, main bearings 30 inches in diameter

A GAS ENGINE THAT DELIVERS A LARGE AMOUNT OF POWER

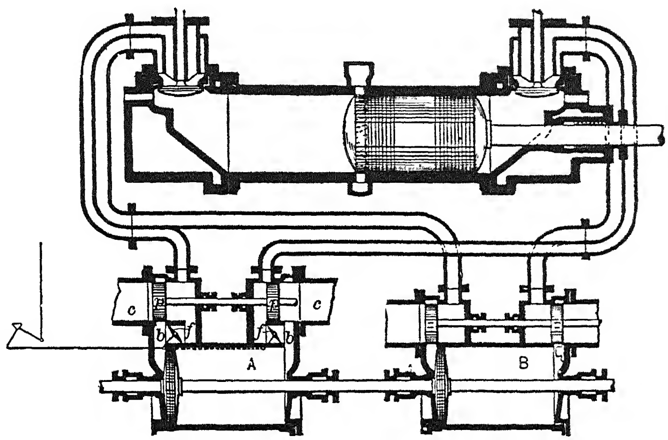




Courtesy De La Vergne Machine Co

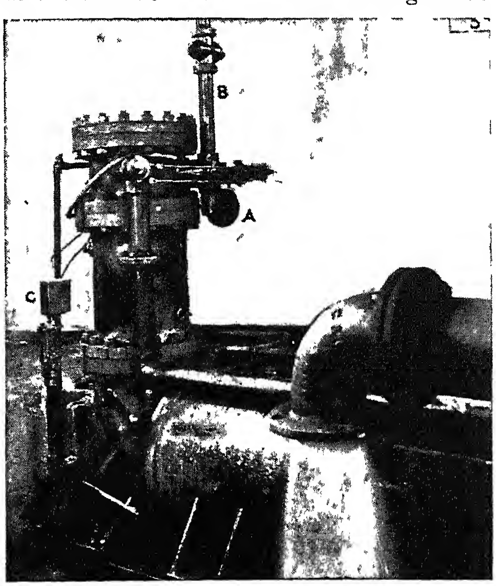
HORIZONTAL AND VERTICAL SECTIONS OF TWO-CYCLE, DOUBLE-ACTING KOERTING ENGINE DIRECT COUPLED TO A BLOWER CYLINDER

with the four-cycle machines that have been described. These machines, while, of course they have the disadvantage of greater complexity as compared with other types, have proved very satisfactory.



CROSS SECTION OF KOERTING TWO-CYCLE, DOUBLE-ACTING GAS ENGINE
A and *B* are independent gas and air pumps driven from the main shaft. The admission of the gas and air is controlled by the piston valves *pp* In this engine each end of the cylinder receives a power impulse every stroke

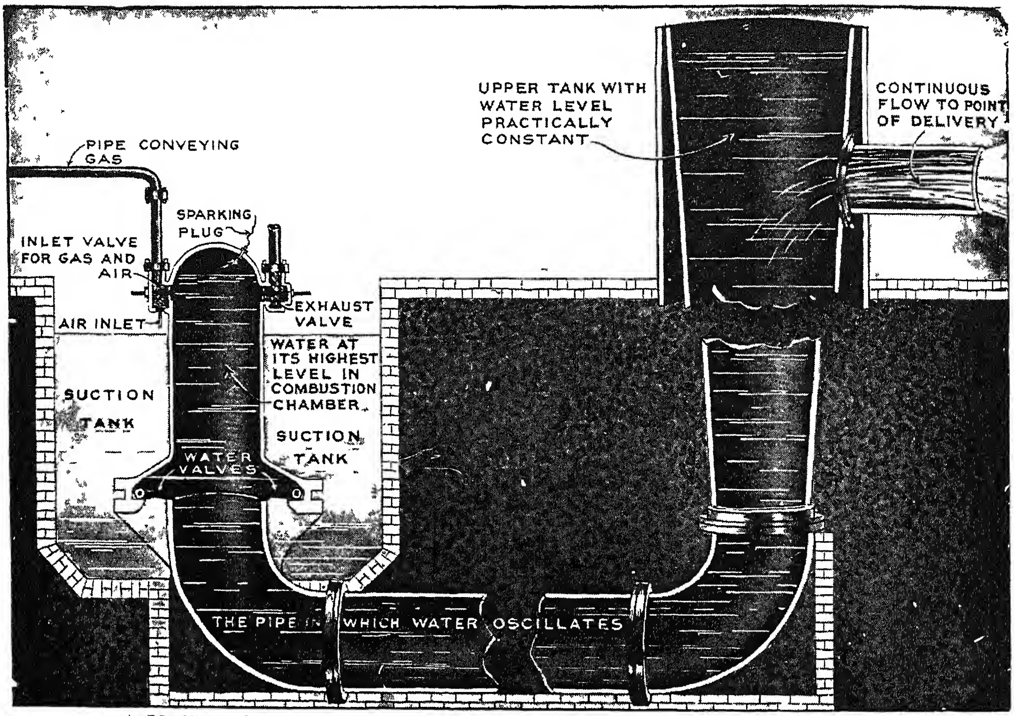
Perhaps the most interesting method of securing power from gas is found in the Humphrey pump, which is really a gas engine in which the piston, connecting-rod and fly-wheel are all acting in unison. In the accompanying illustration the explosion cylinder is shown on the left. It is partially submerged in the suction tank from which water is to be pumped and the water valves must, of course, be submerged constantly. The upper end of the explosion chamber is fitted with an igniter, and with valves for admitting air and gas, as well as an exhaust valve.



A HUMPHREY PUMP AT WORK
In this example the pump raises the water into the combustion chamber through suction pipes from below. *A*, air inlet; *B*, pipe supplying gas; *C*, sparking apparatus.

Suppose now that an explosion has just occurred in the upper end of the chamber and the water valves are closed. The expanding gases will then force the water in the explosion chamber downward and the entire column of water in the pipe moves toward the delivery nozzle, shown at the right, and which is, of course, at the required elevation above the suction tank. Once this long column of water is set in motion, however, it continues to move after the force of the explosion is spent and until a partial vacuum is formed in the explosion chamber. The water inlet valves are on hinges and open inward. As soon, therefore, as the pressure in the cylinder falls below that of the atmosphere the water rushes in, in an effort to fill the partial vacuum. But by this time the water column has lost its forward momentum and starts to swing back, the water inlet valves closing as soon as this reaction is felt.

As the high column of water in the tall delivery pipe sends the water upward into the explosion chamber it pushes the spent gases out ahead of it and closes the exhaust valve. All of the spent gas cannot escape, however, and this residue is highly compressed in the top of the chamber. This compressed gas acts like a spring and in its rebounding expansion it again forces the water column downward in the chamber and again causes a partial vacuum. This second semi-vacuum opens the gas and air inlet valves and sucks in a charge of gas and air. The next backward surge of the water compresses this charge into the upper end of the explosion chamber starting another cycle.



A DIAGRAM OF THE HUMPHREY PUMP AT THE POINT OF HIGHEST COMPRESSION
The connecting pipe and the higher tank are actually twice as long as shown here

The method of timing the ignition is very ingenious. A piston works in a small chamber connected to the combustion chamber. This little piston is raised by the compression of the charge effected by the last upward swing of the water column. The piston is connected to the sparking mechanism and this is so set that ignition takes place when compression is completed. In starting the pump in the beginning it is necessary to charge the combustion cylinder with gas and air by auxiliary means. If the ignition mechanism is thrown out of action while the pump is running, it is apparent that the pump will stop with an unexploded charge in the combustion chamber and it can be readily set in motion by igniting this charge.

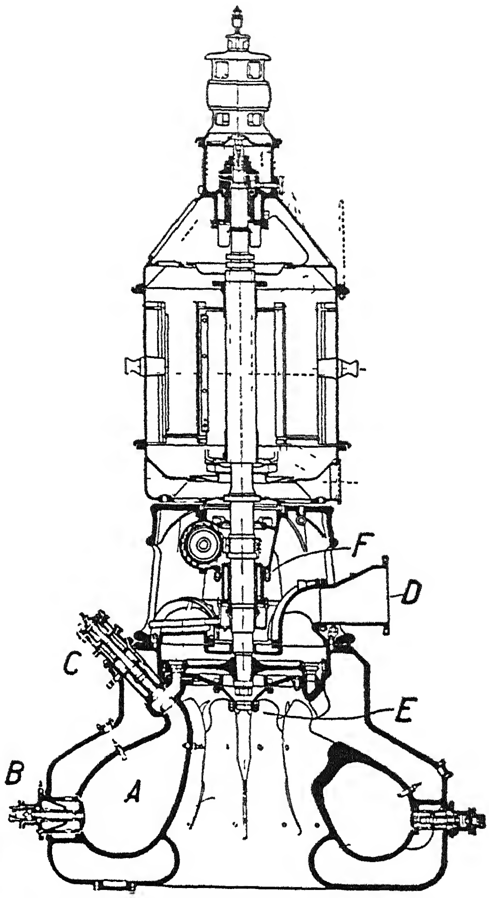
A Humphrey pump has been installed at Del Rio, Texas, which has an explosion cylinder 66 inches in diameter and 41 inches long. The water pipe is 66 inches in diameter and 100 feet long. The pump can raise 26,000 gallons of water in a minute to a height of 37 feet. The pump makes from 12 to 20 explosions per minute and is guaranteed to turn 20 per cent of the heat supplied by producer gas of a given quality into useful work. The pump is used for irrigating purposes.

This form of engine is very simple and will work with a wide range of fuel gas. The working parts are few and there is little to wear out, little to lubricate or to get out of order. There are limitations to its use, however. The simple form of the pump that has been described is confined to pumping against heads of about 40 feet, but Humphrey pumps fitted with discharge valves and with what is known as an "intensifier" can pump water up to a height of 150 feet. But even this height is small compared to the heads often required in industrial work.

The possibility of obtaining power from gas through the medium of a turbine has long been an object of study by engineers. A turbine is essentially a wheel mounted on a shaft and fitted with buckets or vanes in such manner that as water, steam or other fluid or gas is forced against them the wheel will rotate, thus transmitting power to the shaft from which it can be taken off to do useful work.

The first gas turbine to operate in anything like a satisfactory manner was built by Armengaud and Lemale in Paris in 1894. In this turbine a mixture of vaporized oil, compressed air and steam is exploded in a small pear-shaped chamber. The gases due to the explosion rush through a nozzle and strike upon the blades of the turbine wheel which is set rotating with great rapidity. To protect the moving parts from the intense heat generated the combustion chamber and the disc rim and blades must be lined with heat-resisting material. While this turbine did not meet with commercial success, it marked great progress in an experimental way.

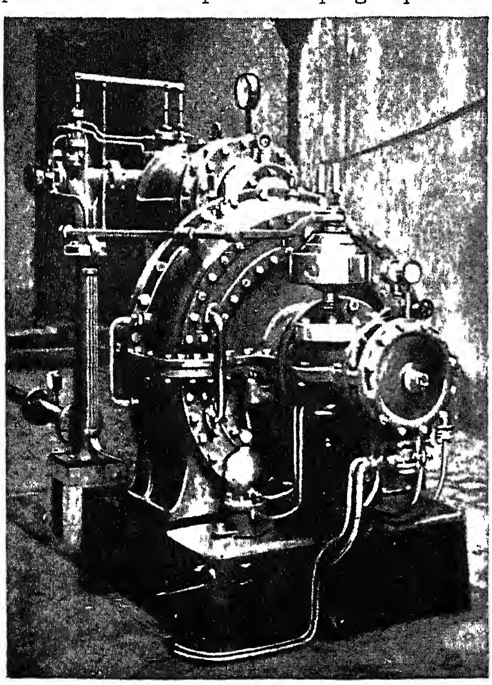
Another important attempt to solve the problem was that of the German inventor Holzworth. In this turbine, a mixture of compressed air and gas is exploded successively in a series of pear-shaped chambers *A* which are arranged in a ring around the turbine rotor. When the explosion occurs in any given chamber, a valve *C* which closes the delivery nozzle is kept shut. But when explosion is complete this valve opens and the gases are permitted to escape and impinge upon the



From Davey's *Gas Turbines*, Constable & Co
THE GAS TURBINE INVENTED BY HOLZWORTH

buckets of the turbine. This turbine differs in principle from that of Armengaud and Lemale in that explosion takes place at *constant volume*, whereas in the former explosion occurs under *constant pressure*.

Another interesting problem that engineers are attempting to solve is the recovery of the considerable amount of energy that still remains in the exhaust gases of the ordinary gas engine. Steam turbines operating from the exhaust of high-pressure steam engines have resulted in great savings, and efforts are being made to develop a gas turbine which will do the same service for the ordinary gas engine. All of these experiments are as yet, however, only potential in their results and much experimentation is still necessary before the gas turbine will reach the high state of development of its steam predecessor.



GAS TURBINE BUILT BY ARMENGAUD AND LEMALE

LOWLY REMNANTS OF AN ANCIENT RACE

INDIANS OF THE ANDES, ECUADOR

MOKI INDIANS OF ARIZONA

DESCENDANTS OF THE INCAS WHO WERE A HIGHLY CIVILIZED PEOPLE FOUR HUNDRED YEARS AGO

UTOPIAS OF THE REDSKINS

Utter Savagery Side by Side with
Imperialist Socialism among the Indians

SOME PROBLEMS OF SOCIAL EVOLUTION

THERE are few persons who have never felt, at some time or other, the romance of history. Perplexed by the problems of daily existence, dulled by the routine of our work, we look back with longing to the ages when human society was less rigidly organized, and life was more adventurous and more picturesque. Our poets, painters, and novelists charm us with visions of the clash and color of the feudal era. Some even go back in fancy to the wilder days of the Celts and Germans before Roman civilization reached them ; and lately H. G. Wells, Kipling and others have given us stories of life in the rude Stone Ages.

A curious error, however, underlies nearly all these historic and prehistoric romances. It is generally assumed that the kind of life depicted has long since passed away, and that nothing now remains but the somewhat colorless industrial civilization which we are all helping to build up and improve. But, as a matter of fact, practically every form of human society that men have ever fashioned can still be found existing on this earth. Our world at the present day is wonderfully interesting, and full of wild, fantastic contrasts. We can travel up the river of time as easily as we can journey across space. Return tickets to the Stone Ages may be had at nearly any railway station or seaport. South America is our next-door neighbor, and north of Rio de Janeiro, on the east coast of Brazil, there is a race of Indians who have not yet reached the Old Stone Age. They are known as the Botocudos.

Like all "Redskins" of America, they really are a race of coppery-hued people ; and, through living in the tropical forest, with its leagues of shadowed stillness, they retain peculiar yellowness of complexion untouched by any sun-tan. Dwarfed in body, with beetling brows and sunken noses, they wander in a state of absolute nakedness on the wooded heights three hundred miles north of Rio de Janeiro. Their only appliances are wooden weapons, and bags of vegetable fiber, and they possess no knowledge of the art of navigation. Lower in culture than the men inhabiting Europe two or three hundred thousand years ago, they do not know how to get a cutting instrument by chipping the edge of a stone, and they use merely bamboo knives and bamboo arrowheads. Their dwellings are branches of trees stuck in the ground, loosely tied together with strips of bark, and seldom made more than four feet high.

Roots and berries, honey, frogs and snakes are collected by the Botocudos, and form their principal food. With their feeble weapons of wood and their extremely low social organization these savages are scarcely more advanced than was primitive man when he girded up his loins and began to contend with the larger beasts of prey for the lordship of the earth. In one respect, indeed, the Botocudos are the most degraded of human races that ever existed. Lacking the power of mind and the ability for social combination which enabled the great hunting peoples to master every animal, these vile and cowardly Indians eat their fellow-men.

The low forms of human existence that remain where life needs no effort

Even the pre-human unit of society, the family, does not maintain itself among them. The union of the sexes is temporary, and the women are treated with extraordinary cruelty.

There is no government save when some wizard manages to get control of several families, and acquires a sort of chieftainship. When he dies or grows weak with age, the families split up and continue their scattered life.

Compared with the communities of ants, whose little cities are the plague of the poor Brazilian settler, the Botocudos can scarcely be said to be social creatures. There is in Brazil a certain kind of ant so numerous, so ravaging, and so invincible that, in the absence of dynamite and other modern means of destruction, civilized man would be compelled to retreat from its territories. Even at the present day it often costs more to destroy the ant hills than the land is worth. Were mankind generally still at the level of the Botocudos, the country would eventually become the dominion of the ant. The insect, by reason of its almost perfect social organization, would triumph over humanity.

Perhaps we shall not go far wrong in attributing the degraded social condition of the Botocudos to a sluggishness of mind mainly induced by the natural fertility of their tropical forests. Food of a sort has always been abundant, and there has been no incessant stimulus to invention.

Many of the native tribes of the tropical regions of South America are — or have been — fierce, low, wandering savages, with no knowledge of agriculture and hardly any social organization. A somewhat similar state of things may be observed in the forests of Central Africa, where also the means of life have been for hundreds of thousands of years too easily purchased. In Central Africa, however, invasions and migrations of peoples and mixtures of races have now somewhat obscured the various lines of stagnation and development. In South America these can still clearly be traced.

To the west of the region of the Botocudos there is a race of Indians, or Amerinds, as they are coming to be called, speaking the Quechua tongue, whose lot is cast in a hard, rigorous climate. They live on the highlands of the Andes. They are scarcely taller than the Botocudos, but their heads are perhaps somewhat more massive. Dwelling in a temperate climate, two miles above the sea-level, these mountaineers have been hard put to it to earn a living. Much of their land is too cold to bear any crop, and it was as shepherds that they entered on the path leading to civilization They caught and tamed the llama, and then went on from their snow-clad heights to till the lower, warmer slopes. The arts of metal-working were discovered, and the crafts of building reached a perfection which has been equaled, in its special way, by no other nation in the whole world. The pottery of the mountaineers is also remarkably fine, and their feats of engineering are considerable.

Setting out with a fund of superstitions common to all the American native races, they arrived at the idea of a Divine Father, and then put their belief in the brotherhood of man into practice with an energy, a thoroughness, and a genius for organization to which no other human society can offer a parallel.

The high type of organized government of South American mountain tribes

On a space of two thousand miles along the western coast of South America there lived at least ten million people, each of whom had a fair amount of food and work apportioned to him by the state. Everything was taken care of by the central government — provisions, medicine, land the exchange of commodities, irrigation works, splendid roads, magnificent cities and help of every kind. All that was asked of the ordinary citizen was that he should do his fair share of work. An overseer was set over every ten families; a headman over every ten overseers; a chief over every ten headmen; and a lord over every ten chiefs. All the lords were ruled by an emperor.

TYPES OF BOTOCUDOS

The socialistic form of government produced a wonderful contentment among the people, and the entire machinery of the society worked with incomparable smoothness. The people were warlike, and they constantly extended their boundaries by conquest. The subject races, however, were treated as equals, and allowed all the privileges of citizens, and they remained contented with their lot.

The treacherous destruction of South American socialism by Pizarro

The empire of socialism thus founded on one of the bleakest spots in South America was destroyed by a small troop of Spanish adventurers under Pizarro. It was accomplished by inviting the Indian emperor to a conference, capturing him and holding him as a hostage, and then murdering him — a foul act of treachery.

Yet the socialistic state founded by the mountaineers, and continued by the Incas of Peru, is not wholly a thing of the past, even now. Three centuries of horrible massacres and tortures reduced the number of Quechua peoples from ten millions to a million and a quarter, and the last known Inca was killed by the Spaniards, with the usual treachery, in 1783. But though the names of the present native rulers of the Indians of Peru are not known to the outside world, the descendants of the ancient emperors still live and rule over two million people on the uplands of the Andes. They meet, it is said, in secret congress, and discuss all matters relating to the welfare of their people. The marvelous force with which the civilizers of the New World have faced adverse circumstances, which would have swept most races from the earth, gives ground for the hope that under a more humane rule and a juster government they may again multiply and resume their high place on the earth.

In any case, their social achievements must ever rank among the finest attempts at the organization of humanity. The ant was not likely to conquer *them.* Their government was, indeed, the nearest approach made in a vast, practical way to excel the wonderful insect communities in their own form of social arrangement.

We have contrasted at length the Botocudos and the Quechua peoples, because these are vividly representative of the two extremes of early social organization. Between the utterly anarchic group and the rigid socialistic community, there is a multitude of human societies of various kinds scattered about the world. There are clans in the Old Stone Age, and tribes in the New Stone Age; loose confederations which have only recently discovered the use of copper; farming races which use iron in a rough and primitive way; and warlike nations inspired by a fierce, picturesque chivalry and still swinging between the barbarism of the dark ages and the despotic captaincy of some strong-handed leader.

The rise of the power of the priest in the earliest ages

Some lands are ruled by a strange and mystic priesthood, like that of ancient Egypt; and not far away from a pagan theocracy is still found its lowly source in the witch-doctors that bear sway over some low, savage, unwarlike tribe. Sometimes we can catch the witch-doctors in the process of developing into a heathen priesthood with little or no political power, being kept in check by a warlike chief who is growing into a monarch. Sometimes the chief himself has certain priestly functions, and we can then trace the old idea of the divine right of a king back to the superstition of an ancestral god from whom the chief is supposed to be directly descended. It is very curious to reflect that the divine right of a king has nothing behind it, in a historic view, except the primitive dread of ghosts.

The tree-dwelling people whose habits appear fantastic travelers' tales

The strangest of all existing communities is found among a curious race of men who inhabit the remote forests of the East Indian Archipelago and part of Malaysia. They are of very small stature, with black skins and woolly hair, and they live naked in the trees. There are unexplored regions where no head-hunting Dyak or Malay will venture, for fear of the tree-people.

From tree to tree, where the branches do not meet and form a bridge, are tied ropes of rattan, and along these aërial forest-ways creep in silence the most primitive race on earth, armed with blowpipes. Tipped with a poison for which no antidote is known, their little arrows are showered down upon any intruder. Of the wildest of these wild tribes, therefore, nothing whatever is known, and only two white men are reported to have seen them — one, an orchid-hunter, escaped with the loss of his men; and the other, a mining explorer, caught a glimpse of them just in time, frightened them by firing his gun, and then ran for his life. There are many travelers' tales of the tree-people, but we are informed that they have only been picked up from Dyaks and Malays.

They are now extinct in Java, their primeval home, where the last-known survivor, Ardi, was employed some years ago in the Buitenzorg Botanical Gardens. His race, however, lives on, under various names, in other large islands of the archipelago, and in the inland forests of the Malay Peninsula. The Samangs of the central Malay forest are the best known. They are true nomads, without permanent homes, and they camp under frail lean-to's of palm-leaves, wherever game is plentiful. Where, however, they are menaced by other races, they return to the tree-tops, building shelters and living in the foliage. Their skill in rope-walking is extraordinary; and their women have been seen passing from tree to tree, carrying cooking-pots, and other effects, with a babe at the breast and small children clinging to their heels.

Tasmanian natives and the light they might have thrown on early man

All that is clearly known of this strange race is that the ties of family love are strong, and that the women are respected by the men. They worship a female deity, who is represented under the form of a mysterious warrior queen, haunting the deep recesses of the forest. Armed with her deadly blowpipe, she will come forth at last, and destroy all the enemies of her people.

Allied by descent to this strangely primitive race were the natives of Tasmania, the last of whom perished in 1877. From what scanty superficial information we have, it appears that the Tasmanians lived only in family groups, with no political organization. There were certainly no chiefs or anyone who could make any agreements binding on even a small group of families. We can only suspect that there were marriage divisions in the various loose hordes speaking the same dialect. Their weapons were the crudest Old Stone Age implements, similar to those occurring in the oldest river-beds of Europe, and their shelters consisted of a single screen of leafy boughs placed to windward. They made fire by rubbing a wooden stick in a groove of harder wood.

The short-sighted destruction which an unintelligent civilization permits

They went naked, covering their bodies with grease to protect themselves from the wet. Five was the highest number for which they had any word. Some tribes only had three terms for reckoning: these were *mery*, *calabawa* and *cardia*, which stand for "one", "two" and "plenty", or rather, anything over two. Their means of navigation was a rude raft, formed of three rolls of tree bark bound together with wisps of grass.

There can be little doubt that in these frail and primitive structures the Tasmanians sailed from Java, by Bali, Timor and other islands, to Australia, and, after colonizing Australia, they voyaged across to Tasmania. It is also very possible that the race to which they belonged worked its way from Asia to Europe, and even inhabited Britain in the days before the English Channel existed. That means that Europeans ruthlessly wiped out in Tasmania a harmless race that received them kindly and that could have thrown much light on the past of civilized mankind. Professor W. J. Sollas, of Oxford, thus criticizes the British government:

"If any other nation than our own had shown the same disregard for a human document of such priceless value, we should be very outspoken in our censure.

Even now, in this twentieth century, it cannot be said that the British government takes such an intelligent interest in the numerous primitive peoples which it has taken into its charge as we have a right to expect from a state having regard for the advancement of learning."

The extraordinary significance of paternal aunts in savage South Sea society

As matters now stand, we are unable to trace with any certainty the evolution of the structure of human society. There are many theories on the matter, but facts of primitive origin are hard to get at; and when they now survive, they are mixed up with elements of later cultures. The Tasmanians would have been invaluable, and their extermination reduces us to guesswork. Several years ago, however, a clue was accidentally discovered among some of the islanders of the South Seas. Europeans had been living for about a century with the natives, whose social organization was supposed to be well known. However, an aboriginal was asked who was the most important of his relations. He answered, "My father's sister." Thus, neither his mother nor his father was accounted the most important person in his life; and now it appears that the paternal aunt is a figure of extraordinary significance in societies which have retained their primitive structure.

The primitive tribe is divided into two parts, and descent is always traced from the female side. This is the state of mother-right, the existence of which has led some men of science to the belief that woman was once the queen of society. It now appears, however, that the tribal division, and the apparent disregard of the connection between a father and his children, are evidence of an extraordinary male tyranny. The whole thing is merely a marriage arrangement, by means of which the old men get all the young wives, while the young men have to be content with an elderly female clan-relative of their father. The cunning scheme seems to be an early development of the pre-social group, where the jealous sire had several wives, and drove his sons out when they grew up.

The elaborate convention of totemism and its effect on social organization

Primitive man used, instead of brute force, the more powerful instrument of convention and custom; keeping the youngest women for himself, he married his sons to the old women of some neighboring family group with which he had become connected. Such, at least, seems to be the social structure which the Tasmanians maintained for many ages; and vestiges of it can still be found among the savage communities of Australia and elsewhere, in which there subsists a Tasmanian element.

The next stage in the evolution of social structure is found among the black South Sea tribes who succeeded to the Tasmanians. They introduced totemism and clan organization, magic and descent through the father. Totemism consists in naming a clan after some animal which the clan eats only at a great religious festival, after performing magic rites which are supposed to make the animal flourish in great numbers. The other clans profit by this care and abstinence from the totem; and each of them in turn watches religiously over the welfare of some other animal, which it also does not eat except at its solemn festivals. Such seems to be the idea of primitive totemism, though the matter becomes complicated when clans take their names from natural objects that have little or nothing to do with the food-supply of the tribe.

The early and widespread establishment of ordeal-barred secret societies

Undoubtedly, totem rites make for social organization; and we find in many parts of the South Seas that chieftainship has been evolved, together with a curious magico-religious system of taboos which gives the leaders a strong command over the people. Sometimes social life proceeds on the communal plan, large groups living together in big clubhouses. A curious feature of this stage of society is the widespread secret societies. From them, as from the lodges of modern freemasons, women and the uninitiated are excluded.

The ghosts of the dead are supposed to be present, and they are consulted by various magical rites. The chiefs are connected with the great lodges, and often use them for political and personal purposes; and there are numerous minor societies.

In the more important societies the initiation is a stern ordeal, the candidates being subjected to severe trials of endurance by torture and hunger that sometimes last for weeks. Mysterious and impressive dances, performed in the moonlight, are a chief part of the function of these primitive freemasons, who often act as a kind of secret police. These primitive secret societies, which today obtain chiefly in the South Seas and among the negroes of Africa, seem to have originated in a conflict between the very low savage races and the higher hunting-tribes.

Organizing power of the North American Indian greater than supposed

In America the totem organization of clans and the communal life in large clubhouses were finely developed. Moreover, the American Indian long since developed into a good farmer in many parts of his continent where nature was neither too harsh nor too kind. So it was probably by retaining the communal structure, while developing the arts of agriculture, that the most advanced American Indian tribes grew into socialistic civilizations. It is popularly supposed that the Iroquois and Algonquin tribes of eastern United States were predatory nomads living entirely by the chase and the scalping-knife. Some tribes were, no doubt, driven back to the hunting stage by pressure from the white settlers, but for the most part they were originally an agricultural race.

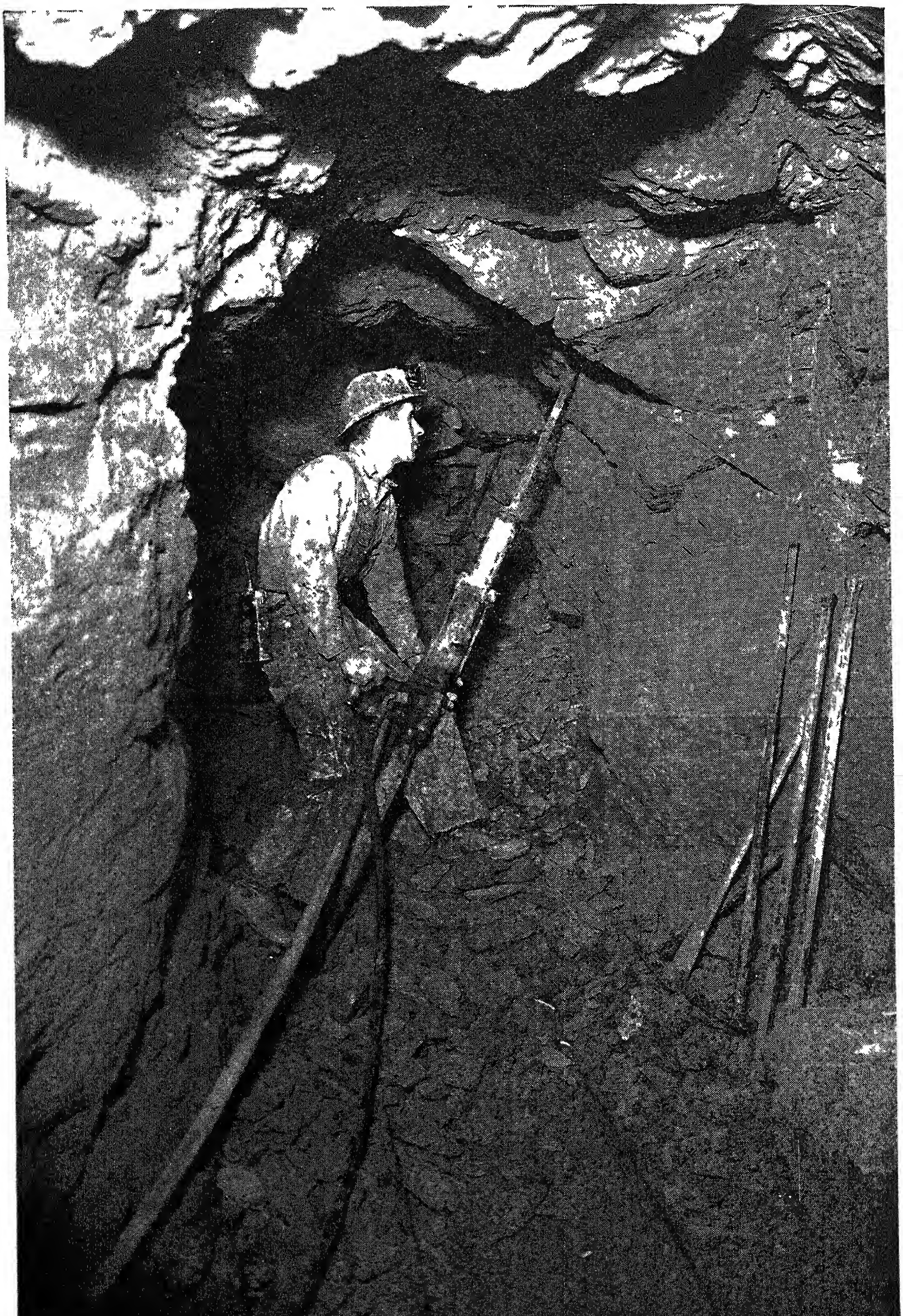
Several nations of North America even had an urban civilization, with actual towns under municipal government. Scattered over the Mississippi basin and thickly crowded in the Ohio Valley are great earthworks, once supposed to have been erected by a civilized people who were destroyed by the wild Indians long before the coming of the white man. It has, however, been proved that the mound-builders were well-known Algonquin tribes.

They planned their towns with public squares, separate buildings for the councilors, the warrior chiefs and inferior chiefs, and a hall for general religious and social purposes. A public bathhouse and a public dancing-yard were found in every central square, and something like a representative organization was in process of being evolved. Some wild tribes east of the Rocky Mountains still disturbed the peace; but if America had not been discovered until the age of the steamship, the Iroquois, who gave their women a considerable share of political power, would have now established a vast empire between the Atlantic and the Mississippi. In New Mexico and Arizona the Pueblo Indians, pressed by the wild tribes of the north, built huge stone fortresses, sheltering the whole community. Still farther south were the highly civilized Mayas, who were conquered by the barbaric and cruel Aztecs.

The Incas not the only Indians far advanced on the road to civilization

Thus we see that the wonderful system of state socialism built up by the mountain race and the Incas of the Peruvian highlands was not a miracle of the Indian mind. In the north, in the center, and in the south of the New World the redskin was marching along the path to civilization, with no help whatever from Asiatic and European culture. In some places he had already reached a solution of the terrible social problems which still perplex us, and in other regions he was well on the way to a system of imperial communism developed out of the communal life of the higher savage stage of culture.

In the Old World the evolution of society was less simple and more varied. Nothing so suddenly perfect as the Inca and Maya civilizations was attained, but social elements and social forces which had been overlooked by the wonderful redskins were discovered and developed by the slower and more comprehensive races of the Old World. Instead of settling down in happy contentment, they struggled on to that idea of a larger progress which they have not yet worked out.



Colorado Springs Chamber of Commerce

Drilling in a gold mine at Cripple Creek, Colorado. Gold was first reported in this area in the 1850's.

THE SYMBOLS OF WEALTH

Searching for Nature's Buried Treasure

NO one who has not seen the wild rush for the scene of a lucky find of gold can realize the madness of "gold fever." It impels great multitudes of men to leave home, kindred, comfort and an established position and to trek into the wilds in the remote hope of attaining wealth and all that goes with it. This has always been so and will probably always remain so as long as great treasures are to be found in the bosom of the earth and men are born with the red blood of adventure in their veins.

The story of one mining camp is the story of all. Someone, possibly a prospector, discovers traces of gold or of silver. As the rumor of the find spreads far and wide, a frenzied mob of treasure-seekers rushes to the place, whether it be in the tropics or in the frozen north. For a time there is seething activity. A good-sized town springs up as if by magic, throbbing with feverish excitement, ecstatic hope and grim despair. In time, however, the vein or deposit fails to yield precious metal in adequate quantities. The disappointed diggers disappear, the buildings become dilapidated, the workings cave in. In a surprisingly short time the place becomes a forbidding wilderness of desolation, sad to look upon and sometimes dangerous to approach.

Some well-known gold rushes of the last few generations

There have been several of these gold rushes in comparatively recent times; those to California in 1849, to the Fraser River in 1857, to Virginia City, Nevada, in the early sixties, and to Alaska in the late nineties are among the best known. Perhaps the most interesting and in many respects the most typical rush was that to Virginia City.

A great vein of mineralized quartz, the Comstock Lode, was discovered here. It was four miles long and two hundred feet or more thick in some places; it contained fabulous amounts of gold and silver. To this barren hillside, over a mile above sea level, there flocked perhaps the most picturesque collection of humanity ever gathered together in one spot. In a few years a town of forty thousand inhabitants had sprung up atop the great workings, which burrowed the hill like a rabbit warren. The doings of the inhabitants were fantastic almost beyond belief; they were set forth with great gusto by Mark Twain, then a reporter for a Virginia City newspaper.

Many of the workings were exceedingly rich; one great lump of ore yielded $105,000,000 worth of gold and silver bullion. A few lucky miners attained riches beyond their wildest dreams, and they became national figures in time. For the great majority, however, there was only a bare living; for a certain number there was bitter poverty, which all too often ended in tragedy.

Virginia City, once so wealthy, becomes a ghost town

By 1890 most of the mines had ceased to pay or had already been abandoned, and soon Virginia City became a ghost town. In the present century, indeed, profitable mining operations have been conducted there by working low-grade ores; the place has also attracted considerable numbers of tourists. But the days of its greatness are no more.

Such, in general, are the ups and downs of men, mines and towns that depend for their existence on the success of gold mining. There are instances, it is true, where the deposits are so large or have been so carefully exploited that the workings give promise of permanence. But even in such cases, the end must be reached some day.

The beauty of gold, the permanence of its luster and its scarcity, have always made men desire this precious metal.

The difference between gold and iron in the matter of intrinsic value

It has been more used for personal ornament than any other metal, while its physical properties also make it valuable for many industrial purposes. But it is because the world has agreed to make gold an "instrument for facilitating the exchange of one commodity for another," and has accepted it as the standard of such exchange, that man has shown such zeal in its discovery and production for so many centuries.

A Scythian traveler who visited Athens during the height of its glory reported that the Greeks made constant use of pieces of gold and silver which they exchanged for commodities. "But," he added, "the only value of them seems to me to be that they make arithmetic and numeration more easy." This Scythian had never seen money before. It was not used in Scythia, where goods were exchanged directly ("bartered") without the assistance of "pieces of gold and silver". He had a shrewd mind, though, for he saw at once what a great many find it very difficult to understand, even after long use of money — that gold and silver serve only as a method of comparing values. Their own value is largely artificial. The world could get along without them, which cannot be said of iron, which is so much cheaper.

More gold produced in recent four decades than in preceding four centuries

"Gold is found in nearly all parts of the world and small amounts occur in ocean water and in many rocks. It is mostly in such minute proportions, however, that it cannot be profitably extracted and only the more concentrated deposits can be utilized and some of these only where natural conditions are favorable. Gold has always been precious and difficult to obtain and never has been found so plentiful as to still the desire for its possession. In its search and exploitation, nature has generally demanded full toll in labor and effort." (Encyclopedia Americana)

In a Bureau of Mines publication, it is estimated that the world output of gold from 1493 to 1938 was some 1,294,974,000 ounces. The astonishing fact is further shown that in the period from 1901 to 1938, more than 50 per cent of this amount was produced It is estimated that in 1939 the world's production of gold exceeded 40,000,000 fine ounces.

The way gold is usually found in nature and how it is extracted

Gold as found in nature is rarely combined with other substances. An exception to this rule is the combination of gold and tellurium, known as "telluride," large deposits of which have been found in Colorado and Utah. Most usually, however, metallic gold occurs imbedded in quartz "veins," as they are called. These veins, called also "reefs" and "lodes," are of igneous origin, sheets of quartz that fill great cracks or fissures in the rock formation of various countries, and are probably coming from the molten interior of the earth. In "quartz mining," so called, the vein is mined like any other mineral, carried to the surface, and crushed under heavy weights or "stamps" in what are called "stamp mills". It is then ground in grinding mills, and the resultant fine powder is mixed with mercury or "quicksilver," as the miners call it, which forms an amalgam with the gold but rejects the rock. The mass is then allowed to settle, the powder rock washed away and the amalgam collected and heated in a retort. This causes the quicksilver to evaporate, leaving the gold to be gathered up and cast into bars. The quicksilver vapor is carried to a condensing apparatus where it returns to its liquid form to be used again in the process.

In centuries gone by many of these great veins were worn away by water and the eroded material carried down into the valleys, leaving rich deposits of metallic gold in the sand and gravel of the beds and banks of the streams. Such deposits are usually the first to be discovered and, by following up the streams to their sources, the "mother lode," or original vein, is found if it has not meanwhile been entirely washed away.

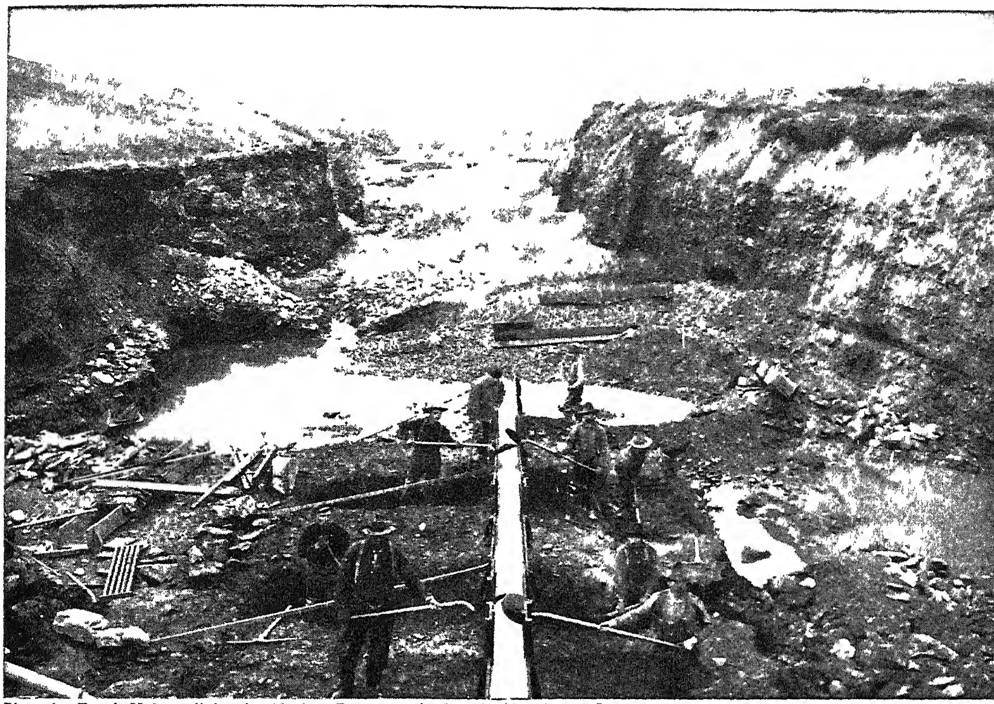


Photo by Frank H Nowell for the Alaskan Bureau of the Seattle Chamber of Commerce

PLACER MINING AT NOME

Shoveling in by hand the early method

HYDRAULIC LIFT, USED IN FLAT COUNTRY: WATER UNDER PRESSURE

It was in this way that the very rich discoveries in California and Alaska were made. Such deposits are usually worked in the following manner. The gold-bearing gravel is shoveled into long sluices through which runs a stream of water. The sluices are fitted with "riffles," or small pockets, into which the gold, because of its greater weight, drops, while the stones and sand are carried along to the waste pile at the end. Sometimes water under a great pressure head is piped to the spot and played upon the gold-bearing ground, forcing it into the sluices. In California huge hills have been washed away by these "giant nozzles," as they are called, and the earth carried into the valleys below, often choking the streams. Rigid laws now govern such hydraulic mining in places where it would be a detriment to other activities, but "placer mining," as it is called, is still practised on the western coast and in Alaska, where the greater part of the fields so far are placer fields. In some cases, however, the gold-bearing gravel is overlaid with subsequent deposits that carry none of the precious metal. In parts of Alaska this covering is so deep that the gravel has to be mined like coal or any other deeply buried mineral. In some cases it is raised by hydraulic elevators so as to bring it up where it can be washed; in others it is excavated by dredges mounted on the end of scows which carry also the washing and separating machinery, and finally dump the refuse at a convenient distance. Some of these dredges are very large and powerful, and can scoop up and handle big boulders. Another method of dealing with alluvial gold is "dry blowing," which is practised in Australia. The alluvial soil is sifted through sieves which let the sand and dust pass, but retain the nuggets. In the early days of Australian mining "dry blowers" became rich in a few weeks.

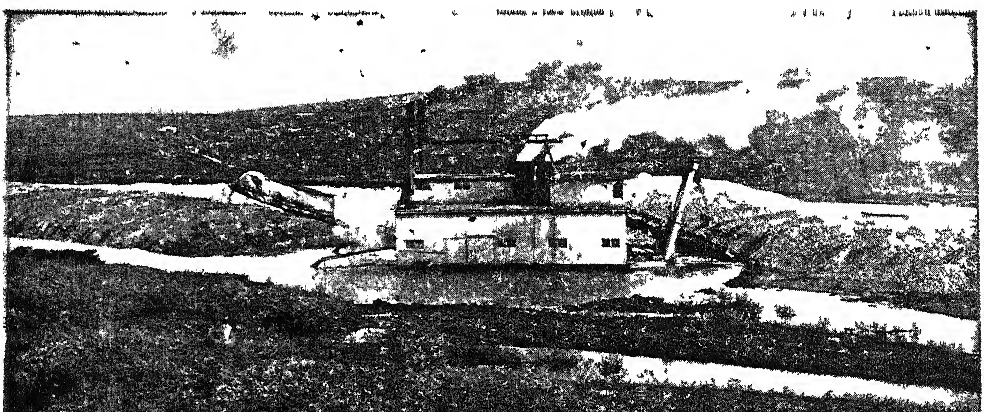


Photo by Frank H. Nowell

GOLD DREDGE, NOME

Method of mining low-grade gravels not rich enough for hand labor

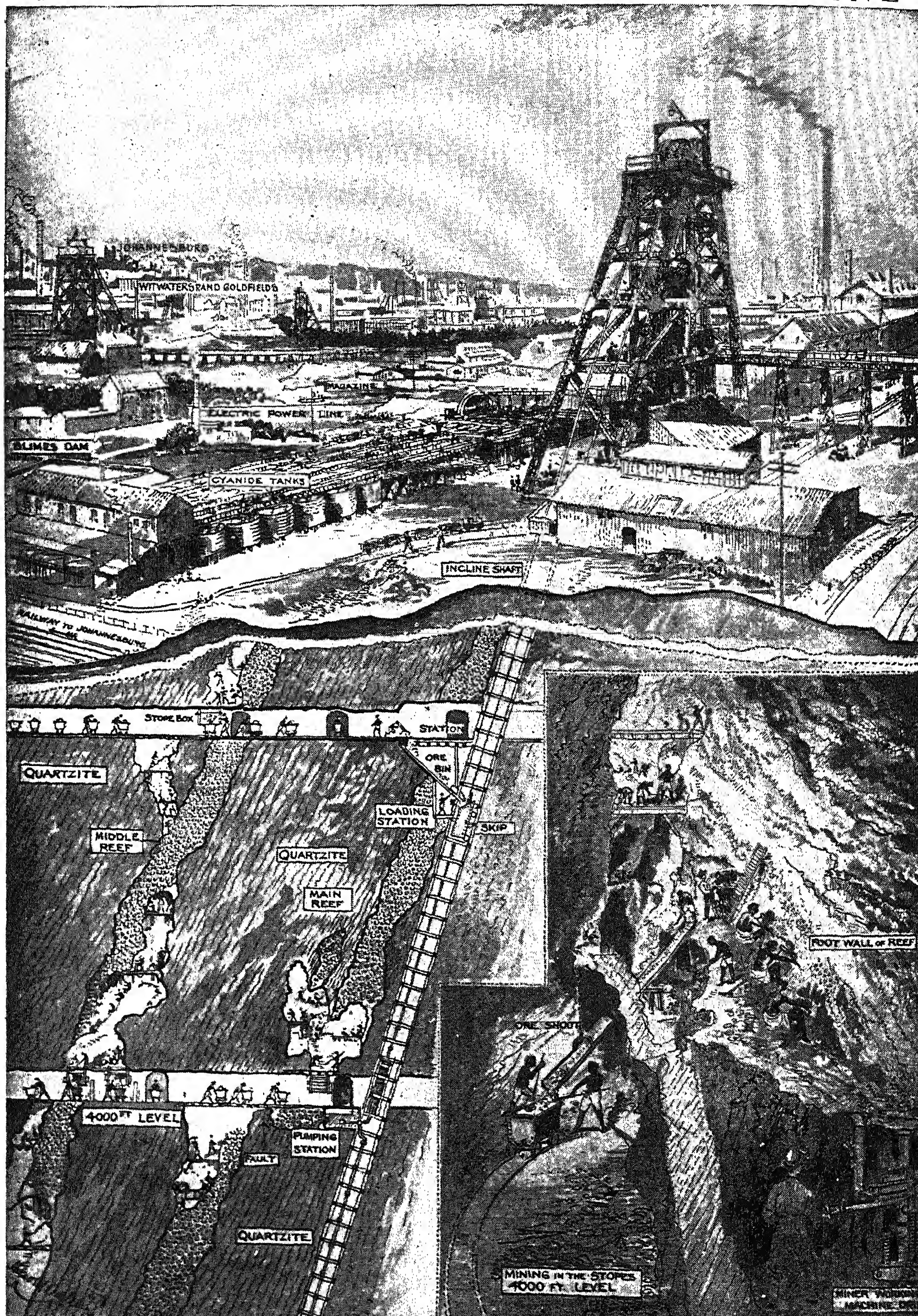
There are several places in America where quartz veins are worked, especially in California, but the largest mines of this kind are probably those in the southern Transvaal, in the range of hills known as the Witwatersrand, or the "Rand," as it is more commonly abbreviated. All along the ridge which shelters Johannesburg, and which stretches for some fifty miles on either side of the city, great mines betray their presence by shaft-gear, black against the sky, and shining, flat-topped hills of dust, the waste product of the stamp mills. As is so often the case, the energies of man have outraged nature. Vanished is the quiet charm of the rolling and peaceful plain with its willow-fringed pools reflecting the sunset. Chimneys belch forth great clouds of smoke, and tin huts, with all their unlovely surroundings, abound. Native compounds are everywhere in evidence, their corrugated iron walls topped by barbed wire entanglements.

HUNTER CREEK CLAIM, A RICH DEPOSIT OF ALLUVIAL GOLD IN THE KLONDIKE

DIGGING AWAY A HILLSIDE OF GOLD-BEARING ORE AT NAKATAMI, SIBERIA

The alluvial gold deposits of Siberia and the Klondike have been the scenes of many valuable discoveries. For example, at the Hunter Creek Claim, in the Klondike, for some time $1500 worth of gold was found every day. The Nakatami mine of Siberia resembles a quarry.

THE WORKINGS OF A RAND MINE



The Witwatersrand Goldfields, popularly known as the Rand, stretch for about fifty miles around Johannesburg. The gold is found in a series of reefs, the lowest of which—the celebrated Main Reef—has given the Rand the position of the premier goldfield in the world. This Main Reef is mined to a depth of over 4000 ft. This picture shows a general view of a portion of the Rand, together with a sectional sketch through an incline shaft and the galleries that run from it.

Let us descend into one of the openings that goes down 4000 feet or more into the bowels of the earth, and follow the process by which the gold-bearing rock is refined into gold bars or "pigs". Over the mouth of the mine is a great steel structure, or "head frame," far up on the top of which are large sheaves or wheels. Strong ropes, passing over these sheaves and operated by powerful steam engines, raise and lower the cage — into which you step very much as into the elevator of a tall and occasionally you bump your head against a low place in the roof. Fortunately, you were wise enough to accept the loan of rough clothes, shoes and cap and need not worry about your attire. At intervals along the passage are sloping cuts which lead to the vein or "reef," as it is here called. Soon we come to one from which light and noises issue and we can see the actual miners cutting out the quartz. In former days this work was done chiefly by hand, but now holes

IN THE HEART OF A GOLD MINE

This is a "stope," an excavation from which the quartz is being extracted either above or below a level, or gallery, in a series of steps. The men are using a pneumatic drill.

building. The signal is given, and down you go with a sinking feeling under your belt. One, two, three or perhaps four thousand feet you drop almost before you know it, the cage stops and you step out and follow your guide through a long tunnel cut in the rock, and electrically lighted. Every now and then you meet a loaded ore-car drawn by black men, on its way to the shaft to be hoisted to the surface. Your feet splash in the water that has collected in pools on the uneven floor are drilled in the face of the rock and great masses blasted out by the simultaneous discharge of dynamite cartridges. The irregular shaped pieces are collected, carried to the hoist, and shot up to the surface to be flung out with a roar and a rattle into the big shed where stands the sorting-table.

This is in the shape of a crescent. The Kaffir "boys" — all Kaffirs are "boys" — who do the sorting in South Africa stand inside the curves. They separate the

worthless rock from that which has gold in it, the latter being distinguished by its markings of milky white. This is thrown on to a moving band which takes it towards a hopper, and here a powerful pair of iron jaws awaits it. They open and shut with a horrid crunch. No rock is too hard for them. They reduce it all to a uniform size that can be dealt with by the stamps.

The new kind of noise we hear now is made by the stamps — thud, thud, thud, like a hundred giants' feet coming down, not all together, as if they were tramping or marking time, but irregularly. You can hear them on a still night many miles away. Thud, thud, thud, down comes their immense weight, over half a ton, stamping on the gravel and crushing the gold out of it. For the rock is gravel by this time. It is now further ground in a "tube mill," a rolling cylinder with very hard stones in it which carry further the process begun by the iron jaws. Finally, it is reduced to very fine sand.

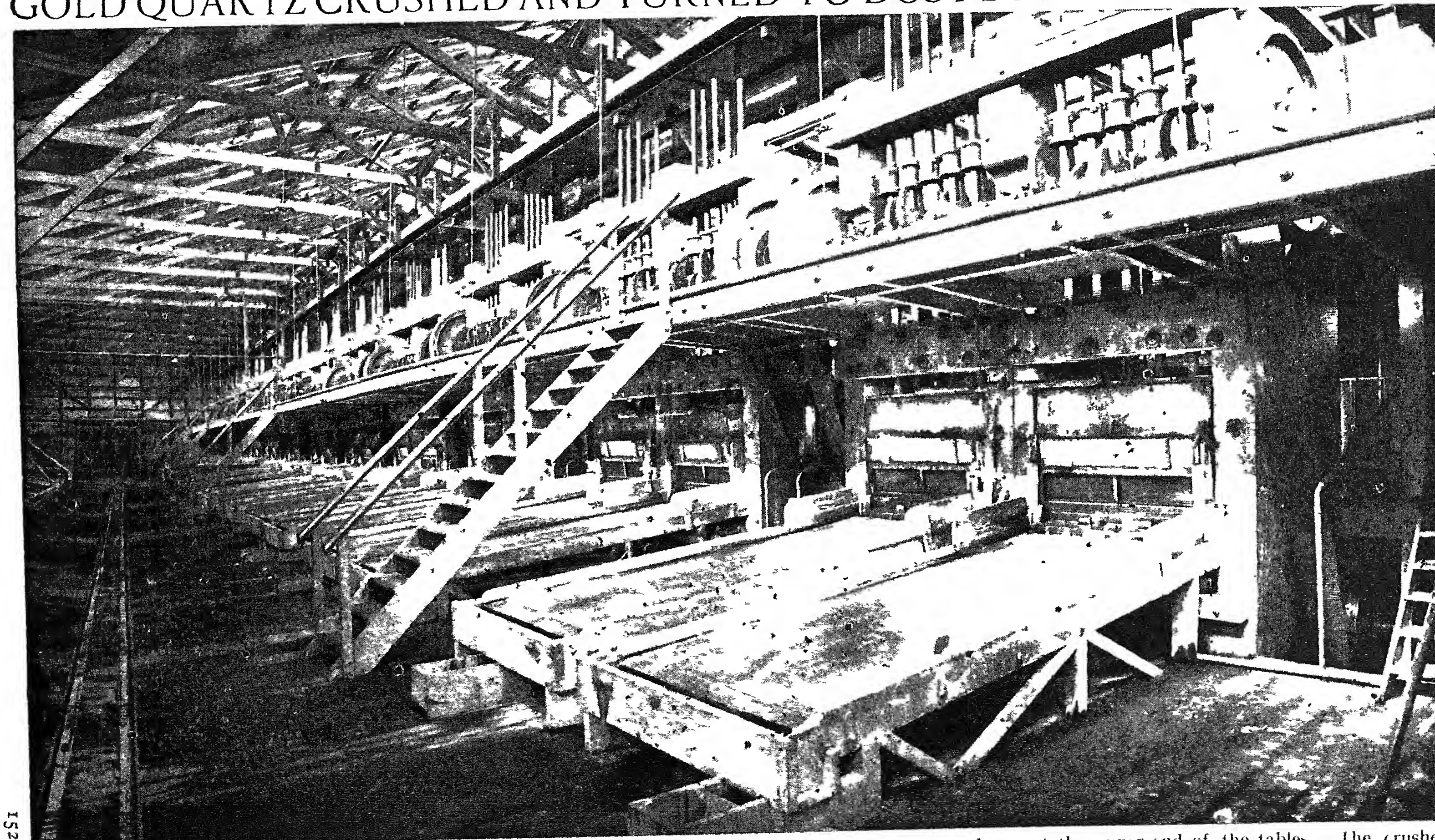
Here is the sand coming out mixed with water. It flows on to a table which is always in motion — a pulsator-table This table is covered with mercury, and to the mercury adheres a large quantity of the gold which glistens bright among the sand. The gold and the mercury together form an amalgam; they are separated later by distillation. It was this amalgam which used to be stolen so freely. Hundreds of thousands of pounds were lost by thefts every year. Now robberies are less frequent. There is a heavy penalty for buying gold through any but a recognized channel, and the seller of stolen amalgam may be sent to prison for five years. There is still, however, a great deal of gold in the sand which has passed over the table. The mercury cannot catch it all. The sand, therefore — now known as "battery pulp" or "tailings" — is divided into three classes, according to its richness, and after that led away to the great vats of cyanide of potassium which are now a feature in all gold mines of any importance. In the vats it remains up to two weeks. Then the liquid is drawn off into tanks filled with zinc shavings. They look like tanks in an aquarium. The shavings might well be seaweed, and one half expects to see a fish's head poke up among them. What happens in them is this: the gold in the solution drawn from the cyanide vats is attracted to the zinc and clings to it. How skilfully man uses for his purpose the attractions and repulsions between nature's substances! In this way almost all the gold which escaped the mercury is detained by the zinc.


GOLD MINERS DESCENDING A SHAFT IN INDIA

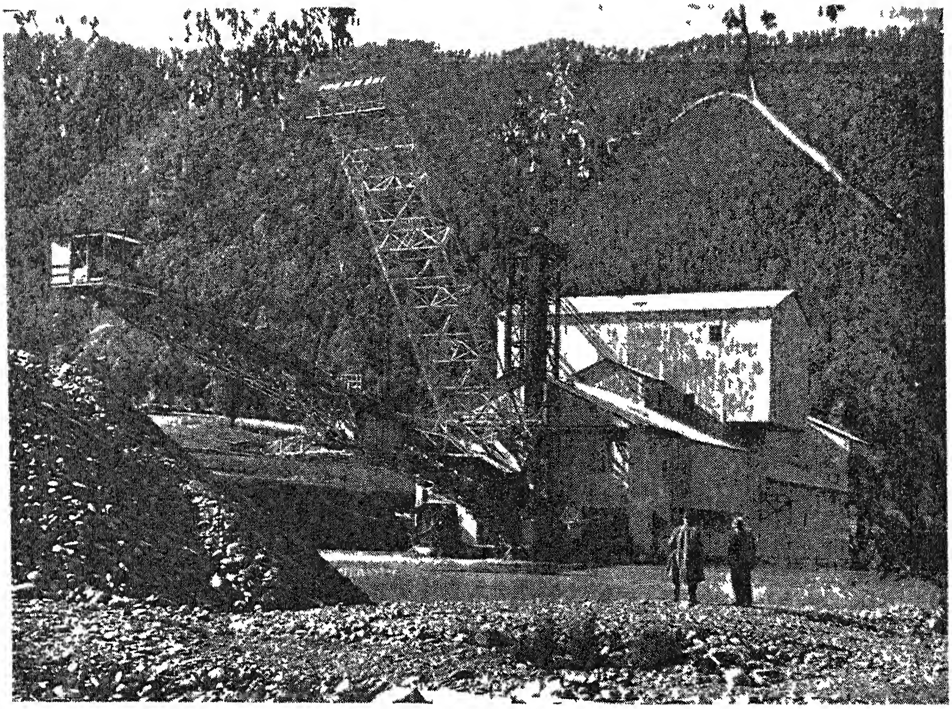
Now in a quiet warm room we can see the crucibles at work forcing the zinc and the mercury to give up their prey. Fire is the agent used. In goes the amalgam, in go the zinc shavings, and presently out flows a stream of liquid gold. It fills molds, and soon becomes a series of ingots, which are taken off to the freight yard, loaded into special railroad cars, and sent down to the sea, thence to be carried to all parts of the world for conversion into a medium of exchange and for other uses.

A very different process that from the popular notion of gold mining, which still imagines "diggers" toiling in the hot sun and coming every now and then across a "nugget," a solid lump of precious metal that can be sold immediately for its weight in gold coin. The only reality which comes near corresponding with that romantic conception is placer mining.

GOLD QUARTZ CRUSHED AND TURNED TO DUST BY POWERFUL STAMPS



The gold bearing quartz of the mine is first broken up into lumps which are then crushed by the stamps shown at the upper end of the tables The crushed rock is then washed down these tables mercury being added from time to time to arrest the gold with which it forms an amalgam



Both photos, Australian Official Photographs

Two methods of extracting gold in Australia's gold fields. Above: a dredge at work in the Ovens River. Below: extracting gold by "dry blowing." The dirt is shaken in a mechanically agitated tray; the dust and dirt are then blown away, leaving gold particles (if any) at the bottom.

Nature's marvelous transformation from wood to coal, and coal to diamonds

Even more than to gold mining does a romantic interest attach to diamond mining, and for the same reason. In each case the product is rare and costly. In each case the early methods of mining gave the adventurer plenty of scope, and enabled fortunes to be quickly made by those who happened upon rich finds. But nowadays the search for diamonds, like that for gold, is no longer an adventure. It has become a business, a highly organized industry. The romance connected with it has altogether evaporated.

Sometimes diamonds are found in the beds of rivers, like alluvial gold. These river stones are of very fine quality, and sell for nearly double the price of other diamonds. But by far the greater quantity of gems which glitter on women's necks and fingers is obtained by mining. India and Brazil used once to be the chief sources of supply, but South Africa has, since diamonds were discovered there in 1867, become by far the largest producer. Diamond comes from the Greek *adamas*, "hard," from which is also derived our word "adamant".

The diamond is, of course, the hardest stone we have, and is therefore used for cutting purposes as well as adornment. Nothing will cut a diamond except a diamond. Nothing cuts glass so well, nothing drills porcelain so neatly, and the dentist will tell you that, when he uses a whirring instrument of torture for hollowing out a cavity, he is using a diamond on your tooth.

Diamonds are formed by volcanic pressure of an unimaginable force. They are the rich relations of common black coal. Charles Kingsley once said: "We may consider the coal upon the fire as a middle term of a series of which the first is live wood and the last diamond. We may indulge safely in the fancy that every diamond in the world has probably at some remote epoch formed part of a growing plant — a strange transformation, which will look to us more strange, more poetical, the more steadily we look at it."

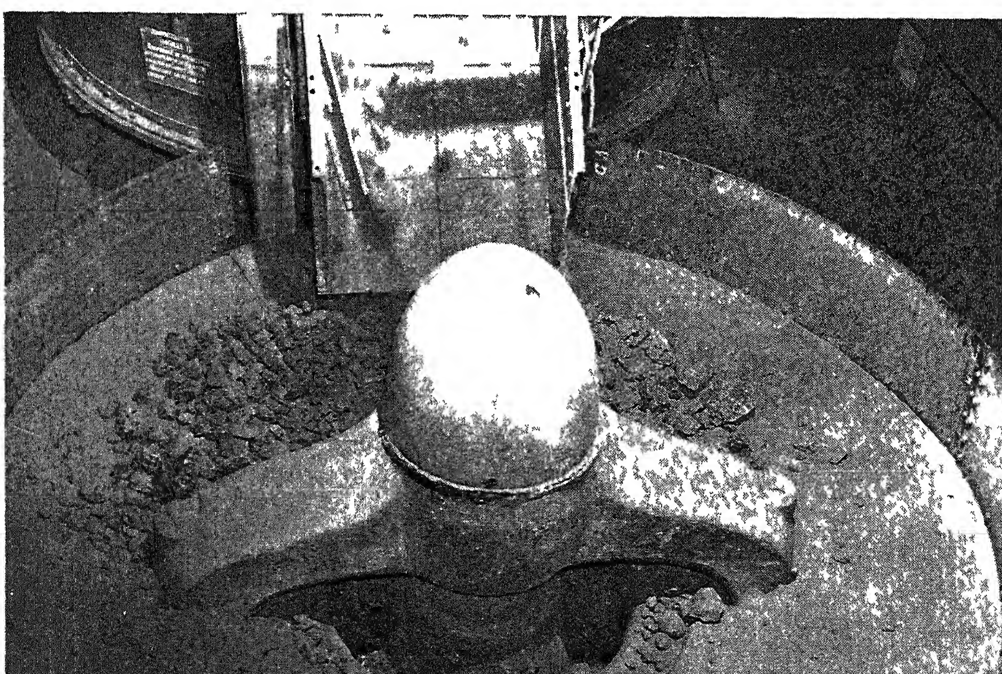
WASHING DIAMONDS OUT OF THE BLUE GROUND BY THE NEW VAAL RIVER

The precious blue ground in which the diamonds are formed

When they are not alluvial, diamonds are found in what is called "blue ground," a bluish-green soil, very heavy in character, which runs in "pipes," or columns,

AT THE FAMED KIMBERLEY DIAMOND MINES

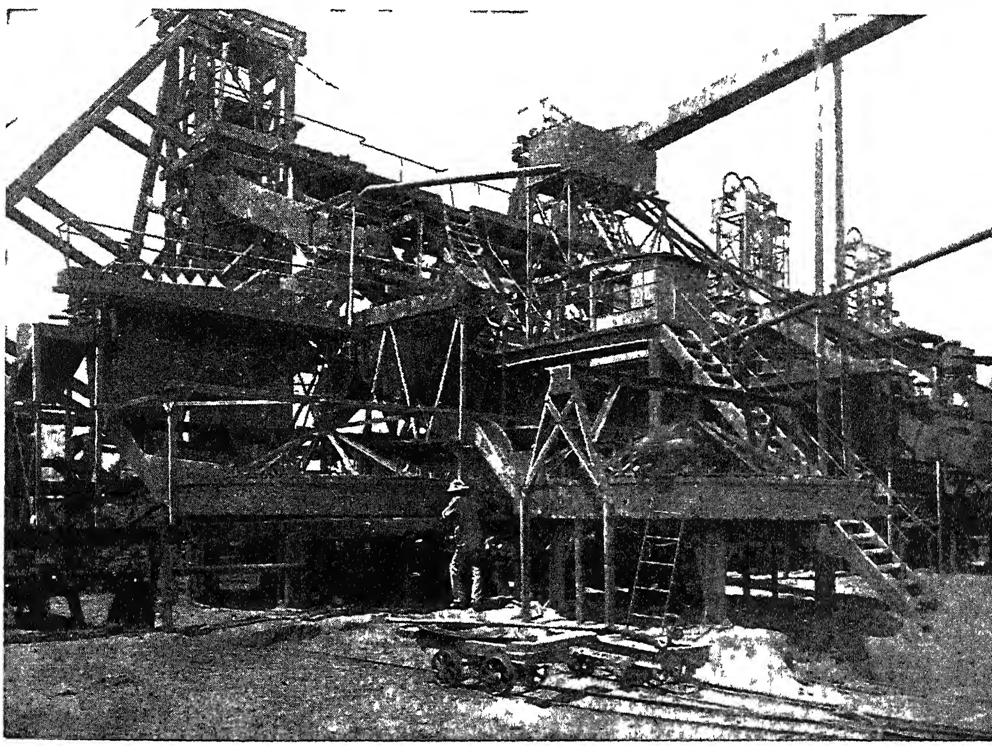
Kafir boys' at the Kimberley mines loading a car with irregularly shaped pieces of blue ground a hard bluish green rock in which diamonds are found The boys can load about forty cars a day



Both photos N W Ayer and Son Inc

To release the imprisoned diamonds, the blue ground is first put through a revolving crusher, like the one shown in the above illustration It is then loaded in cars and hauled to the washing plant

deep down vertically into the earth This blue ground is mined by means of shafts sunk in the ordinary way, and then laid out on great open spaces of veld or prairie called "floors" These floors are naturally well guarded Barbed wire entanglements surround them sentinels with rifles pace round them all night Here the blue ground remains for a long time, to be broken up and made friable by sun and rain The old method was to crush it with mallets but this was clumsy and expensive above them the noise is terrific The wooden scaffolding trembles You feel almost afraid of the monster which the ingenuity of man has created It does its work thoroughly and seems to enjoy it From one pan to another the blue ground passes until the gravel where the diamonds are has been separated from the useless soil For every hundred trucks of blue ground carried up the hill only one truck of gravel is passed to the next process The rest has been washed and chewed away



THE WASHING PLANT OF THE DE BEERS DIAMOND MINE, KIMBERLEY

It was found that the air and the weather had the same, and even a better, effect than the mallet So it is simply spread out on the ground and left, the only treatment applied to it is that in some cases it is turned with steam plows Sometimes it lies out for a year or more before it is ready to be dealt with When that time comes, it is loaded on to small trucks, and carried up an artificial hill, from the top of which it is dropped into the washing-pans

The pans revolve continually, and they are also provided with teeth, which crunch and grind the hard lumps As you stand

Follow the truck of gravel, and you will see how the diamonds in it are picked out from among the worthless stones Take up a handful and your unskilled eye cannot distinguish between them For the diamond in its natural state is not the sparkling gem which you see in the jeweler's window The sparkle only comes when it is "cut" in Antwerp or in Amsterdam Here in the truck it looks very much like any ordinary stone The expert sees that it is not rounded, however, it is eight-sided Also, it is heavier than the ordinary stones.

The endless band that drops stones and diamonds into water

Machinery is required, therefore, to collect the heavier stones from the gravel and let the lighter ones pass away. The machine is a marvel of invention. It is called a "pulsator". Already we have seen a pulsator-table at work in the shed at the gold mine. This is on the same principle — the principle of the beating pulse. The truck turns out the gravel into a hopper, an endless band catches it, carries it aloft, sifts it, grades the stones into six sizes with perfect accuracy, then drops them down into troughs six feet long and about two feet wide. With the stones water flows in, and the whole mass moves incessantly with uncanny jerks. Put your hand into the water and on the stones. It feels as if some animal were underneath, breathing in quick, unquiet gasps. Jerk, jerk, jerk, all the heavier stones are slipping down to the bottom. All the lighter ones are drifting to the end of the trough, where they are washed away. The heavier ones fall through a grating at the bottom.

But not all these heavier ones are diamonds. The hundred trucks of blue ground were reduced to one truck of gravel, and now the one truck has been divided into five parts, one of heavier stones, four of lighter, valueless pebbles. But many of the heavier stones are pebbles also. These have to be weeded out; and the medium which man calls in to assist him in detecting the impostors is — grease.

The shining slab that retains the diamonds and lets the pebbles go

A slab shining with grease is moving to and fro. At the upper end the stones are dribbled on to it. The grease discriminates nicely between the weight of the diamonds and the weight of the pebbles. The former it holds; the latter it allows the water which runs over the slab to carry away. All the stones that are sticking to the grease are diamonds — dark, glistening, eight-sided diamonds, as beautiful to some eyes, when they have been dried and polished up a little, as the glistening cut stones are in ring, or necklace, or tiara.

This slab, however, lets some of the smaller diamonds slip by. So the stones which are washed off here are gathered up and dribbled on to a second slab. And even those which are rejected by this second slab are sometimes examined by Kaffir "boys" in case the slabs should not be doing their work carefully enough. Out in the sun there is a heap of stones on a sack. Black men are looking at handfuls of them. They would spot a diamond at once if they saw one. But they are not finding any in that lot. The grease has allowed none to escape from its clinging embrace. So closely does it cling that the diamonds are not picked out of it by hand, as one would suppose.

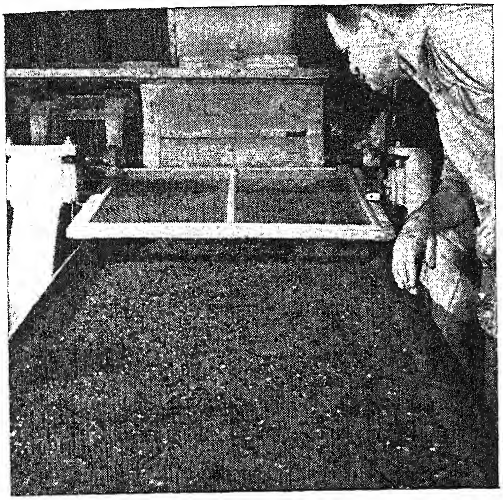
The precious medley that is poured into the boiling cauldron

The whole of this extraordinary mess is scraped up, grease and stones together, and dropped into a pot. This pot goes into a cauldron of boiling water; it turns round and round until the grease is all washed away. Now the pot contains only diamonds, unless by accident there have got into it, as there often do, a few heavy pebbles which are of no value. Up to now, the separation, the testing, has all been done by specific gravity, so there is room for some doubtful stones. The next, and the final, process is to sort out the true from the false by hand.

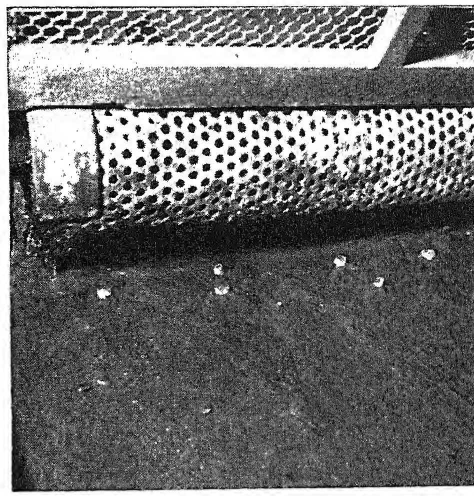
This is done in a room full of light, both for seeing the difference between diamonds and pebbles, and also — equally important — to prevent the men who sit at the sorting-table from stealing any of the stones.

They are all black men, except the overseer. Their table is white, without a speck or stain. They work quickly, manipulating the stones with long knives. The white overseer sits all day and watches them. They are conscious always of his vigilant eye. Even if they did steal any of the diamonds, they would find it much harder now than it used to be to dispose of them. Buyers, as well as sellers, are punished when illicit diamond-buying is found out. "I.D.B." is the short name for it in Kimberley; in the old days fortunes were made by those who made it a regular practice.

FROM CRUSHED ROCK TO DIAMONDS



Fragments of crushed blue ground—rock that contains diamonds—are washed down long tables, like the one shown on the left. These tables are covered with grease and kept in constant motion.



The greased surface of the table holds practically all the diamonds contained in the crushed rock. Very few diamonds indeed are washed away together with the many fragments of waste matter.

Photos, N. W. Ayer and Son, Inc.

Experts sort out the last bits of waste matter by hand; when they have finished their work, only diamonds are left. Here is the product of one day's work at the mine by many hundreds of men.

The ways of the clever diamond thieves of South Africa

All kinds of tricks, some amusing, some disgusting, were resorted to by diamond thieves. To get them out of the mine offices Kaffirs used to swallow them.

One scoundrel had as many as three thousand dollars' worth inside him in the year 1895. They used also to cut holes in their legs, and conceal diamonds in the wounds. Heavy penalties had to be imposed, therefore, upon any person dealing in diamonds, except through licensed dealers. Three years' imprisonment is the term that can be inflicted. This has had its effect. I.D.B. has become rare.

At the office in Kimberley, where the diamonds are kept until the special car used for their conveyance carries them away, precautions are naturally taken against robbery. No one can visit this part of the De Beers plant without a permit. No one, even when this permit has been obtained, can obtain entrance until a little shutter in the iron door has been opened and an eye has looked out to see if the visitor's appearance is satisfactory. But, once inside, you are free of the place so long as you obey the injunction on all the walls: "Visitors must not touch."

The captivating charm of the diamond in its translucent depths

Here men casually turn out tin boxes with thousands of dollars' worth of diamonds. They are so used to them that they handle them like nuts or beads. But they never seem to grow hardened to the beauty of the finest cut stones. They take up an exquisitely cut "pink" or yellow gem with marvelous color in its translucent depths. They gaze at it with tender pride. Certainly no one has any idea of the charm of the diamond who has only seen it in the jewelers' shops.

The invasion of Holland and Belgium, in 1940, practically stopped diamond cutting activities in Amsterdam and Antwerp, which had retained their preëminence in the art since the fifteenth century. It is a trade which requires exceptional skill, and is kept in a small number of hands. In Amsterdam there were about 19,000 people employed all together in the various processes; in Antwerp, about 4000. Since the enforced decline of the two great European centers, New York City is foremost for diamond cutting.

About half the weight of a stone is lost in the process of making it ready to wear. "Rose diamonds" are cut from the eight-sided stones, the "rose" referring to the style, not to the color. "Brilliants" are cut from diamonds with curvilinear faces. Very large stones can be divided. The largest white diamond known was taken out of the Premier Mine, near Pretoria, in the Transvaal. It was called the Cullinan, from the name of its finder, and weighed $3024\frac{3}{4}$ carats, or 1.37 pounds. Its size was 4 inches long by $2\frac{1}{2}$ inches broad, and $1\frac{1}{4}$ inches high.

Naturally, the cutting of such a stone is a matter which requires much thought. It must be made the most of. Nothing must be lost. The planning of the Cullinan partition took two months. Another nine were occupied in cutting it into nine large gems, which in 1908 were presented to King Edward VII to be placed among the English crown jewels.

The diamond is useful in various manufacturing processes

Diamonds are not merely a luxury that proclaims the prosperity of the wearer; they are also extremely useful in various manufacturing processes. Since the diamond is the hardest substance known to man, it is used for grinding or cutting or boring into hard metals or other hard substances. Whole diamonds are sometimes inserted into appropriate tools; sometimes they are cut to fit; sometimes they are crushed first and then molded into the desired shape. Diamonds make ideal bearings for watches. They are also used for wire drawing; a tapering hole is cut in the diamond and the metal is then drawn through this hole.

The diamonds used in industry are stones that contain flaws; they may be imperfectly formed or poor in color. The fragments left from the cutting of good diamonds are also used in industry.

THE ALLERGIES

What They Are and What to Do about Them

by

HERBERT K. DETWEILER

PERHAPS you know someone who never comes back from a horseback ride without wheezing and feeling as if he were smothering. Another person discovers that whenever he plays with his dog, he starts to sneeze and his eyes and nose run. Or a youngster may break out in itchy blotches when he eats eggs. These responses are unusual, because most people can ride on horseback, play with dogs and eat eggs without suffering ill effects.

When an individual reacts abnormally in such cases, we say that he displays an altered or out-of-the-ordinary response to an ordinary substance: the hair of the horse and dog, the white — the albumen — of the egg. An altered response of this kind is called an allergy, and the sufferer is said to be allergic. People once thought that allergies were rather rare. We now realize that about one person out of ten is allergic.

The scientific study of allergies first became possible when research workers found that they could produce allergic symptoms in guinea pigs. To all outward appearances a guinea pig injected with a dose of albumen is not affected. But if in ten days the animal receives a second dose of albumen, he soon begins to sneeze and to breathe with difficulty, just like a person with asthma. If the dose were large enough, he might have convulsions and die. We say that the guinea pig has been artificially sensitized to the albumen.

The human being who sneezes violently when he inhales pollen in the air, or who breaks out in blotches when he eats eggs is naturally sensitized to the pollen or the albumen. The tendency to develop this sort of sensitization is inherited.

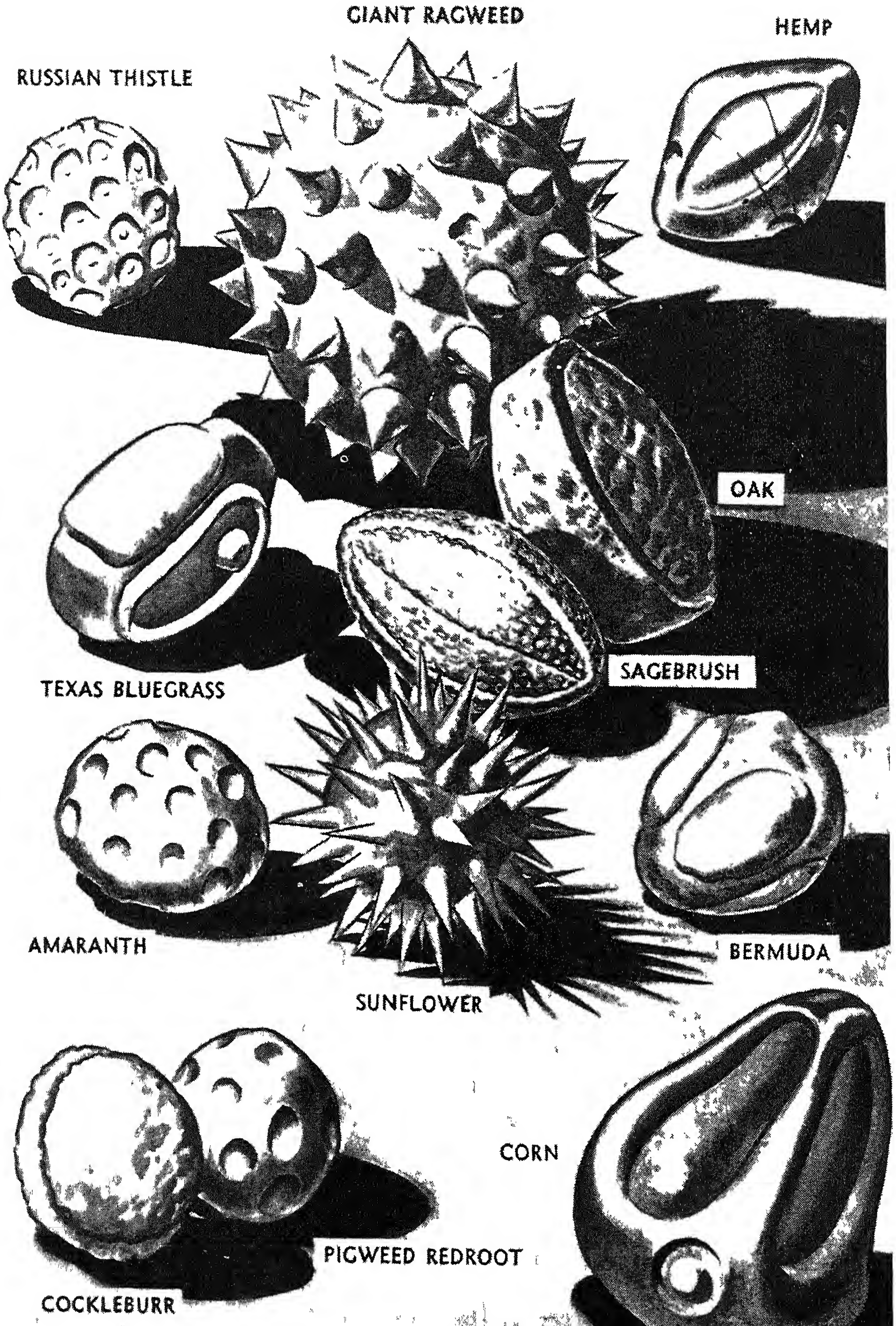
The symptoms of allergy may first appear at any time from birth to old age, but the great majority of cases are encountered before the age of forty. By far the largest number occur in childhood or adolescence. The actual sensitization takes place when the person is exposed to a large quantity or a concentrated dose of the offending substance at a time, perhaps, when his general health is below par. However, we do not know definitely why one baby may develop an allergy the first time he is given cow's milk, and why another will show no symptoms until he reaches school age.

The symptoms vary according to the part of the body where the allergic reaction

U. S. P. H. S.

Collecting pollen on the roof of a New York building. After the slide has been removed from the apparatus, a careful pollen count will be made. Allergists utilize the count in their treatments.

POLLEN ENEMIES OF THE ALLERGIC



Wide World

These dust-like pollens, highly magnified here, all produce allergies. They are nearly indestructible and they can travel great distances. Some of them have been found 250 miles or more offshore.

takes place. The critical areas are the nasal passages, the eyes, the bronchial tubes and, to a lesser extent, the mouth and skin.

If the reaction occurs in the nose and the eyes, the symptoms are itching, irritation and watery discharge from the eyes and nose, with sneezing and stuffiness, so that breathing through the nose becomes difficult or impossible. These symptoms may appear in spells (paroxysms) or may be more or less continuous. The patient soon feels generally miserable and finds it difficult to concentrate on his work, or to sleep. This is the typical picture in hay fever which, as everyone knows, is caused by an allergy to the pollens of certain plants which pollute the air.

When an allergic reaction comes as an attack of asthma

The reaction that comes as an attack, or spasm, of asthma is confined to the bronchial tubes. Let us suppose we are dealing with a child who is allergic to cat hair. Not being aware of this allergy, the parents have given the child a kitten as a present. That very day or night the child begins to cough and his breathing is wheezy and difficult. He can not breathe lying down. Even breathing through the mouth does not help. The chest heaves with each breath and there is great difficulty in expelling the air. Breathing is accompanied by a whistling or snoring sound. This condition usually begins abruptly; it may end in an hour or may continue longer. Hay fever and asthma symptoms may occur at the same time, or at different times.

A third type of allergy makes itself felt with the sudden breaking out of hives or itchy lumps in the skin. There may also be a pronounced swelling of soft tissues such as the lips or the eyelids — a condition often referred to as giant hives. A still further sign of allergic response may be the appearance anywhere on the skin, but most commonly at the bend of the elbows, behind the ears and on the hands, of a scaly rash called eczema. This rash may be caused by taking certain foods or drugs or by coming in contact with a substance or plant to which the person is allergic.

Children are particularly allergic to foods. Eggs, milk, fish, lobsters and oysters are likely to produce symptoms; so are wheat, corn, rice, rye, peanuts, almonds, coconuts, celery and strawberries. Many people are allergic to cottonseed or flaxseed. Cottonseed oil is used in some salad dressings and in making lard substitutes. Flaxseed is frequently found in certain breakfast foods.

Food inhaled in the form of dust or vapor may cause an allergy

Food is most likely to bring about an allergic response in adults when it is an inhalant, that is, when it is inhaled in the form of dust or vapor. Thus flaxseed sometimes becomes an allergic agent when it is inhaled by those who feed it to livestock, or by nurses who make up linseed poultices.

Plants that are pollinated by insects do not cause allergy. Unfortunately the pollens of a great many plants are wind-blown and these pollens are particularly apt to produce allergic symptoms. They usually cause hay fever, but asthma is often present as well. Pollen allergy is naturally seasonal. Trees such as maple, oak, birch, poplar and willow cause symptoms in April and May. Grasses like blue grass, timothy and red top bloom in June and July, while ragweed pollen, the most troublesome of all, is prevalent from mid-August to the end of September.

Other common inhalants are the hair and dandruff of domestic animals such as dogs, cats, horses and rabbits. The feathers of geese, ducks and chickens, particularly those used in making pillows and cushions, are frequent offenders. Cases of asthma and nasal allergy are frequently traced to the inhalation of orris root; this is used for dry shampoos and in the manufacture of face powder and dentifrices. House dust is a frequent cause of trouble, particularly that found in woolen rugs, curtains, upholstery and bedding. Many are allergic to silk, so that stockings or blouses made of real silk may cause hives and other skin irritations wherever there is direct

contact with the skin. Sheep wool is also a frequent offender in this way.

Persons suffering from allergies may find unfavorable conditions in industrial plants. They may become allergic to the spray used in coating paper in lithograph plants. Men engaged in growing tomatoes in greenhouses have been affected by the spore of a plant (*Cladisporium fulvum*) that is a parasite on the tomato plant. The spores occur in the air as dusty clouds when the mature plants are being discarded. The dust that is raised in grinding and similar processes may cause mechanical irritation of the mucous linings in the nose and bronchial tubes, even though no allergy may be involved.

Some persons are allergic to wheat only when they inhale the flour

Pastry cooks and bakers sometimes become allergic to the wheat flour that they inhale in the course of their duties. Usually they do not become so sensitive that eating food containing wheat causes symptoms. However, they can not inhale the wheat dust without suffering attacks of asthma or nasal irritation.

Some persons have been found to be allergic to certain drugs used as medicine. They can not take even a fraction of an aspirin tablet without suffering a most violent attack. The same thing may occur with quinine, ipecac and several other drugs.

In certain cases an allergy is caused when the skin comes in contact with an offending substance. This condition is called contact allergy. Many a housewife has discovered that her hands will become sore and irritated if she picks the leaves of her primrose plant. A blistery and scaly eruption will appear and will not clear up until she gets rid of the plant. I have seen a young man whose hands were covered with a rash soon after he became a teller in a bank. He was allergic to the nickel in the coins that he was handling. Gardeners who handle tulip bulbs often suffer in the same way. Dyes in dress fabrics, chemicals used in the manufacture of leather wristwatch bands, plastics in garters and in nail polishes and other cosmetics have all caused allergies.

A person with an allergy can not always tell just what substance is to blame for his trouble. The doctor has to find out and he usually does so by skin testing. This is usually regarded as one of the more modern developments of medical science; yet the first skin test was performed by a Dr Blackley in England in 1873. The method did not attract general attention, however, until just after World War I.

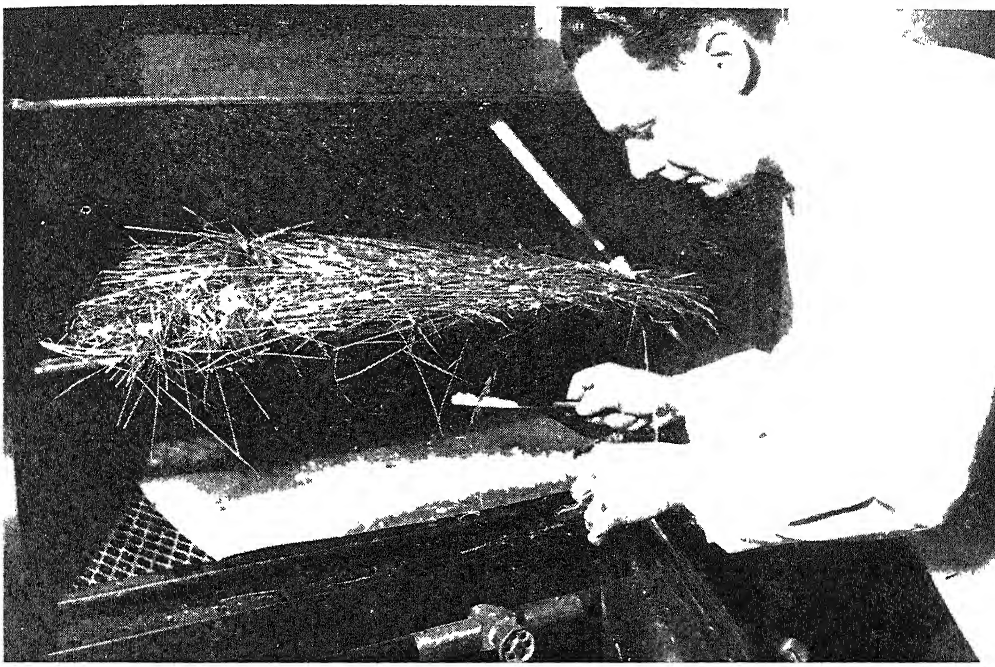
The simplest form of the test is as follows: The skin on the inside of the forearm, or other suitable place, is cleaned with alcohol. With a blunt knife or sterilized needle scratches are made, about an inch apart and one-eighth of an inch long. The scratches penetrate the outer skin but are not deep enough to cause bleeding. A small amount of a suspected substance is placed on the first scratch and rubbed in gently with a drop of solvent. A similar amount of suspected substance number two is placed on the second scratch and rubbed in. Other suspected substances are applied, each on a separate scratch.

After fifteen to twenty minutes, if the person is allergic to one or more of the substances used, a raised area on the skin will be seen around the scratches containing the offending materials. The raised spot will vary in size from the diameter of a pea to that of a dime, or it may be even larger. The outline is irregularly star-shaped, and the whole is rather pale, like the early stage of a mosquito bite or a hive. Surrounding this hive, or wheal, as it is called, is a pink area caused by congestion of the tiny blood vessels of the skin. The wheal feels itchy.

The intradermal test is more sensitive than the scratch test

In another kind of skin test — the intradermal test — a very tiny quantity of the suspected substance, in sterile liquid form, is injected *into* the skin. This method is more sensitive than the scratch test; however, it must be used with great caution. In some individuals who are extremely sensitive, it may cause serious symptoms, such

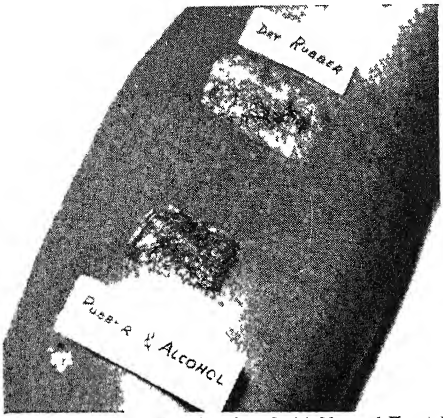
PREPARING SERUMS AND CHARTS



Artificially maturing hay-fever pollen in an incubator. The dry pollen drops into the container beneath; the pollen is then made into a liquid serum that can be injected into a patient.

Both photos, Wide World

Allergists consult a daily chart, showing the amount of pollen in the air, before they inject serum; the dosage will vary accordingly. The pollen-collecting machine shown above is used in preparing such a chart. The air flows through the funnel; the pollens and other particles it contains drop on a slide.



Harold H Briller, from Jewish Memorial Hospital

A laboratory worker in a chemical laboratory developed a mysterious rash An allergist suspected that rubber gloves were responsible, the contact test shown above proved that this was so.

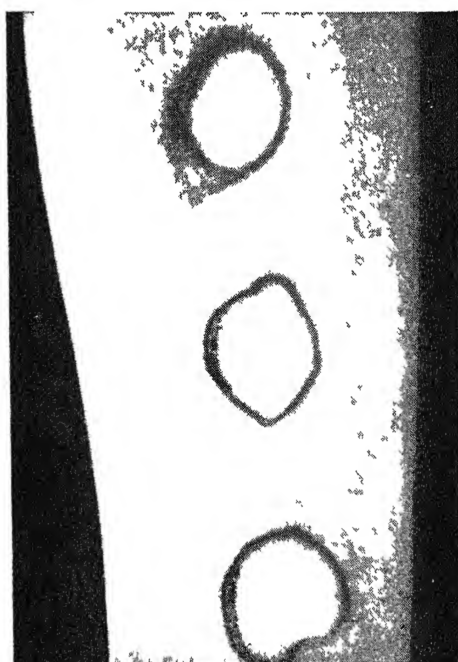
as congestion of the nose, eyes and mouth, and hives over a wide area of the body. Congestion may even extend into the bronchial tubes, causing difficult breathing.

Skin testing has been very helpful in revealing the exact cause of allergic diseases. It is remarkably reliable in the case of allergy due to pollens and animal materials However, it is not always dependable in identifying food allergies Sometimes it reveals nothing even when the doctor is almost certain that a given food is responsible for allergic symptoms. In such cases the doctor has the patient try different diets, omitting the suspected food or foods from each diet in turn. Finally he is able to provide the patient with a list of offending foods that he must avoid.

Some people have learned by personal observation, without consulting a physician, that they will remain free from allergic attacks if they eat no nuts or shellfish or other foods. If the items that they omit from the diet are non-essential, no harm can result. But if such foods as milk, eggs or wheat are involved, one must be careful not to unbalance the diet. In such cases it is best to consult a doctor. If an essential food is causing the allergy, he will take steps to desensitize the patient to this food in a way that we shall describe later. The physician will also provide added vitamins if he finds that it is necessary.

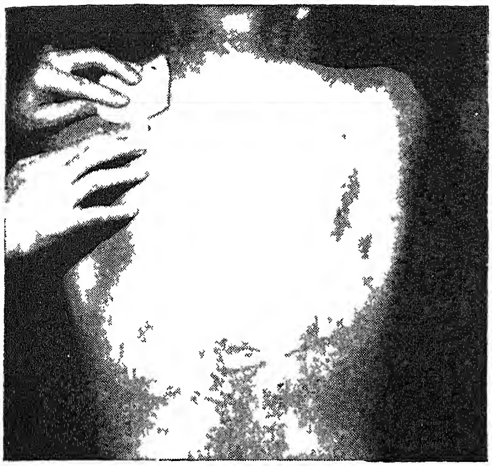
There are special skin tests to detect contact allergy. A minute quantity of the suspected material is placed on the unbroken skin in the normal area. The skin is covered with a moistened pad of cotton, which is kept in position by means of adhesive tape. After forty-eight hours, the patch is removed. Where allergy exists, a rash similar to the original one is found at the place of contact. This is called a patch test.

The interpretation of the various types of skin tests is not so simple as it may seem to be. A positive skin test does not of itself prove that the substance involved is responsible for the symptoms of the person being tested. For example, the patient may show a positive reaction to the pollen of grasses. Yet he may never show any symptoms in the months of June and July, when such pollen is present in the air. In other words, there must be a connection between the positive test and the patient's symptoms before we can determine the

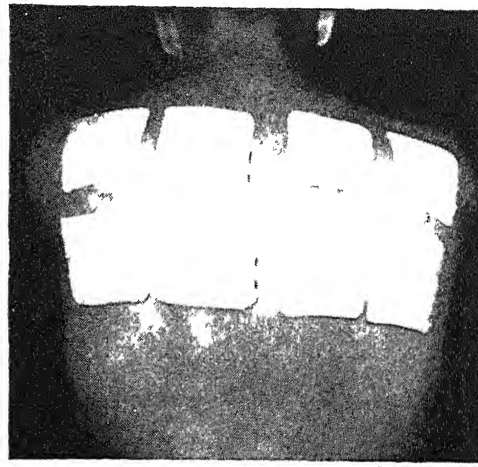


Harold H. Briller, from Jewish Memorial Hospital

Scratch test made on the arm of an allergy sufferer. The scratches penetrated the skin, but were not so deep as to cause bleeding. Suspected substances were rubbed into each scratch.



A patch test A cotton pad set over the suspected substance is kept in place by adhesive tape



U S P H S

Allergy sufferer undergoing simultaneous patch tests for no less than eight suspected materials

cause of these symptoms.

The physician who can successfully interpret the tests is a master detective There is the case of the asthmatic child with a skin reaction to orris root. The doctor discovers that the child's mother has a dry orris-root shampoo once a month. He also learns that the child's asthmatic attacks coincide with the mother's visits to the hairdresser. The doctor is not baffled by the case of the onion-sensitive man who has stomach upsets and asthma and who is sure that he is eating no onion. The case is solved when the patient learns he is getting enough onion in soups to cause the symptoms. Our doctor-detective knows that when you lick a stamp, you are exposing yourself to fish glue, to which you may be allergic. He knows that some people, allergic to the hair of rabbits, are wearing felt hats made of rabbit hair; that other people, allergic to cottonseed, may be particularly fond of sardines packed in cottonseed oil.

Having detected the cause of the allergy, the doctor sets about curing the condition by removing the cause. This he attempts to do by a process of desensitization. The usual method is to inject under the skin a very small trace of an extract of the offending substance once or twice a week. The doctor increases the dose each time until the patient is able to tolerate a large amount without effect. By that time the patient's system has become so accustomed to the allergy-producing substance that there is no longer any response to it.

This is the principle underlying the modern treatment of hay fever and asthma due to pollen allergy There are two ways in which it is applied. In the pre-seasonal method the course of treatment is given each year for the two- or three-month period immediately preceding the pollen season. In the perennial method the inoculations are given throughout the year at intervals of three or four weeks.

The inoculation method may also be used in the treatment of allergy to animal hair and dandruff, house dust, foods and other substances. The results are usually satisfactory if the extracts used are made from the specific substances causing the symptoms.

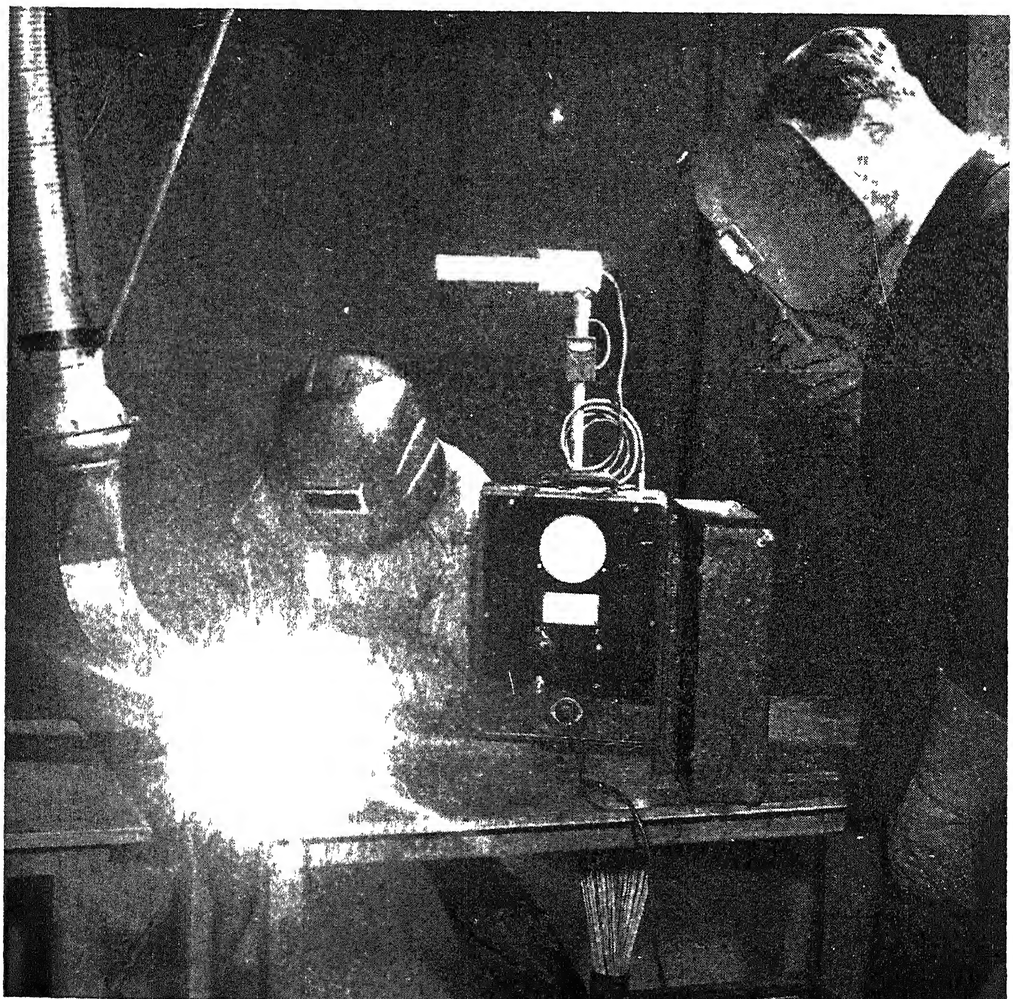
In the case of foods, and particularly with children, it is often preferable to desensitize by giving a tiny dose of the offending food by mouth along with the other foods at one of the meals each day. This is known as oral desensitization The dose must be extremely small and the increase each day must be almost imperceptible. The treatment must be carefully supervised by a physician highly skilled in this specialty.

It is obvious that all this bother is justi-

fied only where the food in question is essential to the diet. In all other cases it is simpler and quite satisfactory to omit the food entirely. This brings us to the second principle in the treatment of allergy, namely avoidance. It may be advisable, in the case of plant allergy, to move during the blooming season of the offending plant into a region where it does not grow. It might be better to sleep on a sponge rubber pillow than to take inoculation against feathers. Face powders that contain no orris are now available.

Drugs play an important role in the treatment of allergy. A hypodermic injection of adrenaline will relieve an attack of asthma or hives for some hours. Certain drugs, such as benadryl and pyribenzamine, will relieve the symptoms of hay fever in many cases. They may be taken orally, of course under the direction of a physician, who must watch carefully for undesirable reactions.

All in all, there has been a gratifying advance in our knowledge of the allergies, and the medical profession has been able to offer an increasing measure of relief to those who suffer from allergic reactions.



U. S. P H S

The electrostatic precipitator shown above helps determine the extent to which the welder is exposed to fumes in the course of his daily work. If he is sensitive to such fumes, he may develop an allergy. Electrostatic precipitators are used in industry as an effective means of disposing of dust particles.

THE MODERN HOUSE

by

JOHN A. HARTELL, B.Arch.

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THE MODERN HOUSE did not appear without warning. Many of the features which characterize it are rooted in the past, and before proceeding to the main discussion it would seem well to examine some houses which are not modern. Figures 1 and 2 offer us general views of two such houses, built in New England before the Revolution. Both are appealing in design, restrained and honest, effective in proportion and in detail. And there are many equally charming houses among those still standing in this country which date from that period and the period of the early Republic. Such houses are justly admired today, but perhaps not all of the people who admire them realize that life as it was lived in them when they were built would seem unbearably primitive to us.

The Capen house (Figure 1) originally contained four rooms, the hall and the parlor placed like the rooms at the front of the plan given in Figure 4, and the two rooms of the same size on the second floor immediately above these. This was a typical house of the day, but in many cases additions were erected at the rear, giving the rooms labeled kitchen, chamber and pantry on our plan, and somewhat later the dependencies of the house were frequently strung out behind the house as indicated here. This was true particularly of the colder parts of New England. In the case of the farms the dependencies were much larger in relation to the house than in

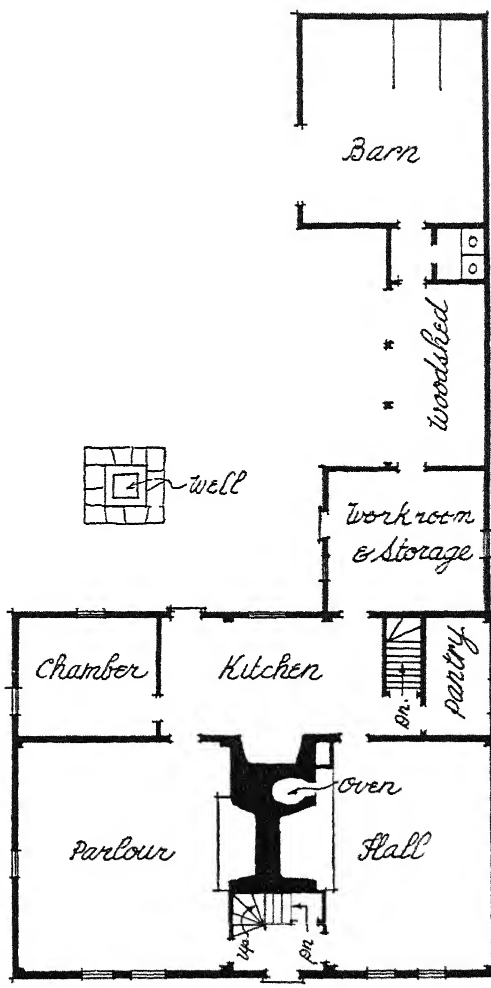


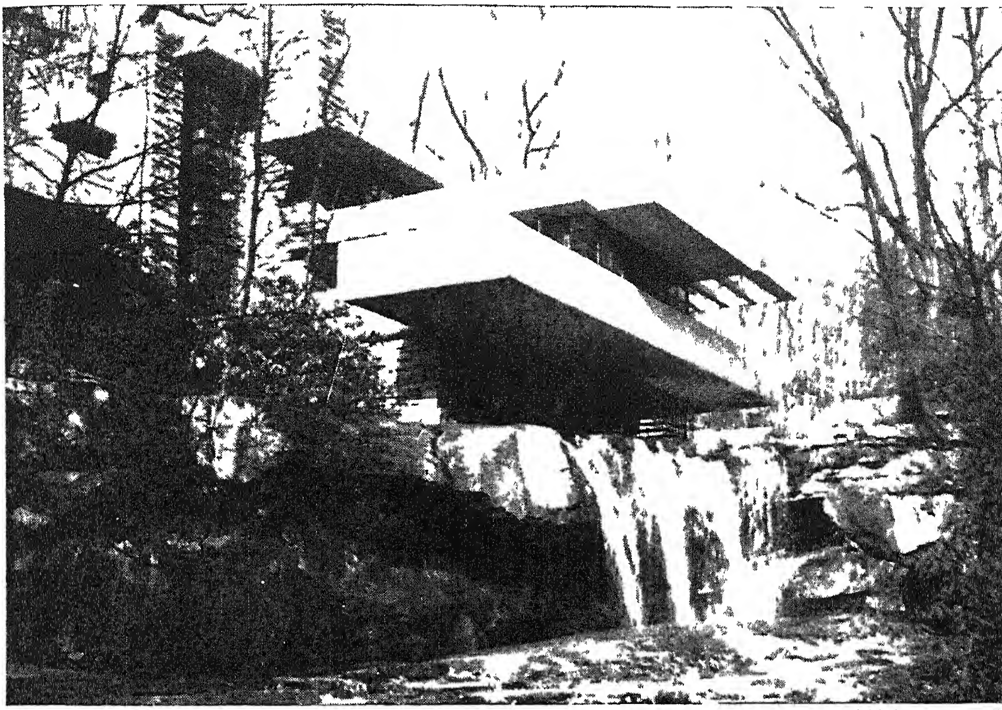
Fig. 4. Plan of an early house in a New England village.

the village house such as this plan represents But even the village houses had barns for the owner's carriage and carriage horses. The layout shown here made it possible to get wood for the fireplaces and to bed down the horses without going out from under cover on a bitter winter's night, and further, since the ell was placed so as to break the force of the coldest winds, it protected the house itself. In those days men had at least a small farm on which to raise the things necessary for their own families, or if they bought their provisions they bought in quantities. Barrels of apples and potatoes and turnips were stored in bins in the cool cellar. Ham and beef were smoked and the bacon cured as a part of the household routine and the women were experts at jam and jelly, for food had to be preserved while it was plentiful for use during the winter months.

Once the Indians and the country itself had been mastered the colonists had begun to build houses in the medieval tradition very much like those from which they had come in England, but before long alterations aimed at taking care of the special needs of the new country crept in. There were no architects or general contractors or sub-contractors. Houses were designed and built by carpenter-builders. The earliest of these had been trained in England in the medieval tradition. They took apprentices and the latter were guided by the traditions which had developed in each locality and by the excellent carpenter's handbooks which had begun to appear. Such books were collections of suggested designs for architectural details such as doorways, cornices or mantelpieces, and, at times, designs for whole buildings, a church perhaps, all based not upon the old medieval traditions but upon the style of architecture known as Georgian which had become prevalent in England. To take it from the beginning, a man wanting a house in those days would go to the carpenter-builder and discuss with him what small variation he might want in the local, customary way of laying out a house and then they would agree upon terms. The next step was the lumber. There were a few sawmills in New England, using water power, even before 1700, but in the villages remote from a river used for logging, the lumber for the new house might very well be procured in log form, from the owner's wood-lot perhaps, and be sawn into planks and hewn into timbers by the carpenter and his help. And when the cellar had been dug with hand shovels and the foundation walls laid up with stones out of the surrounding fields and the chimney begun with bricks from the local brickyard, the timbers were erected into a frame and pinned together with wooden pins and the planks laid to make the floors. The frame would then be covered and the doors and windows fashioned out of the same wood, cut on the spot, using nails and hardware made by the local blacksmith. Except in those cases where the water-powered sawmill did the roughest part of the labor, the house was a work of handicraft, made with the adze, the saw, the hammer and the plane out of the materials which were right at hand.

Houses at this date were arranged, as the plan will show, so that there was a fireplace to heat each room and, in the kitchen to serve for the cooking as well. The weekly baking, done in a chimney oven, entailed as much hard labor as goes into the whole week's housekeeping today, and the washing, done in portable wooden tubs with water heated in the fireplace kettle and with homemade soap, perhaps at the end of a long winter afternoon by the light of a whale oil lamp or a homemade candle, was no easy job. When America was first settled the fireplace was the standard heating equipment in southern Europe and it remained so until the day of central heating, but the people of colder, northern Europe had evolved a stove made of porous, heat-absorbing tiles glazed on the outside. These stoves, fre-

ARCHITECTURE THAT COMMUNES WITH NATURE



Museum of Modern Art N Y

A house built over a waterfall at Bear Run, Pennsylvania The architect was Frank Lloyd Wright

Pittsburgh Plate Glass Co.

Large window units have been used in a corner of this living room to give a fine view of the river.

HOUSE OF THE CIVIL WAR PERIOD

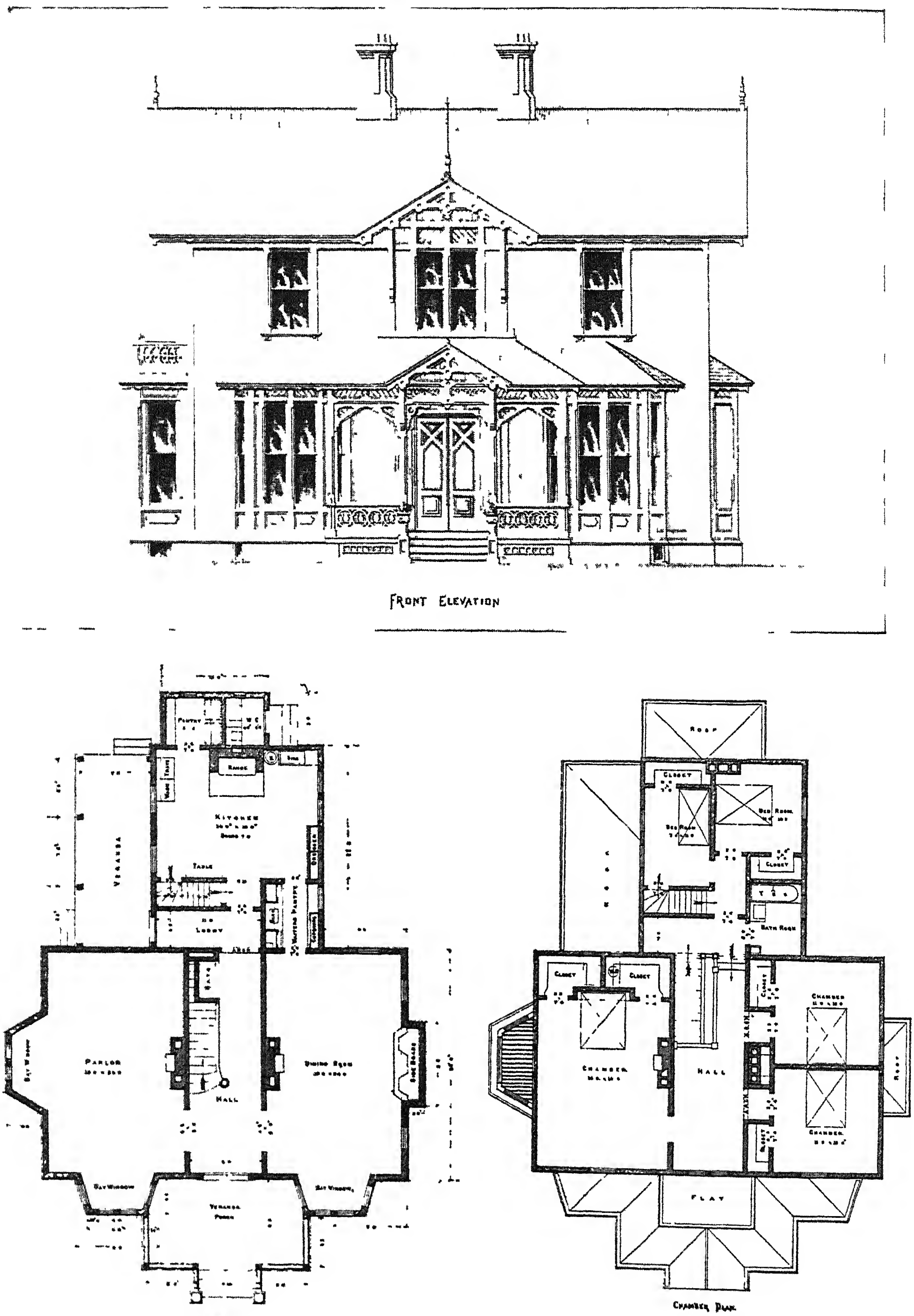


Fig. 5. Front elevation and plans of ground and second floors.
From Woodward's National Architect, 1869.

And there is something else new: this house was designed by an architect. His training, perhaps, was not the equal of that of our architects of today, but he was definitely not a builder. The designing and the executing of the design had now become separated. The new system was here. True, a great many of the details of the finished woodwork inside and outside the house were still custom-made to the architect's drawings, but at least they were made with machine tools in the shop, not fashioned by hand on the job. On the whole, the builder of these houses did not fashion them by hand. He bought so much standard lumber from the lumberyard, so much standard heating, plumbing and lighting equipment, and so much finished, shop-built woodwork and assembled all of these into the completed house so that after some paint, some stain and some varnish it was ready for the owner.

It was to a good degree a factory product and since that time the building industry has been developing and extending that idea. The parts which are assembled into the frame and the finish and the equipment of our dwellings have become more and more standardized. It is possible for instance, to buy from one manufacturer an electric dishwasher-sink, an electric stove, a washing machine and an assortment of cupboards, broom closets, etc., all standardized in dimension so that they may be spread along one wall of a kitchen and all stand out a uniform 25 inches from that wall. The factory, moreover, has given us a selection of entirely new materials for building—celotex, linoleum, gypsum, panels, plywood, various products of synthetic plastics and dozens of others, among which is the glass brick. These prisms of translucent glass, slightly larger than an ordinary brick and hollow at the core, are finding enthusiastic users. As an outside wall they offer a pleasant patterned surface to the eye while furnishing good insulation and letting a tempered diffused light into the house. They are laid up with mortar like common bricks which they exceed in strength, so that the people who live in these glass houses may, if they choose, throw stones. And the factory has continued to add to the supply of mechanical conveniences it began turning out some forty or fifty years ago. The very latest addition to the model kitchen, for instance, is the waste disposal unit or garbage grinder. This electrically driven device reduces all manner of waste, including bones, to a pulp which may be discharged down the drain pipe and into the sewer (Figure 6).

But the factory would not have had its great influence had it not been for good transportation. Transportation has permitted the factory to follow its natural impulse and grow, until our lumber, our hardware, our plumbing and heating equipment, and all the others are the products of a comparatively few great industrial organizations. There is some disagreement as to the lasting economic value of such a degree of centralization. There are also those who contend that the building industry is not sufficiently centralized. They recognize that the factory and power-operated tools are used in building homes, but they hold that the parts which are assembled into the house are not sufficiently standardized and the process by which these parts are now distributed and assembled is inefficient.

Men of this opinion point to the automobile industry, and it might be well here to discuss the automobile and the house briefly. The car of 1910 cost perhaps $3,000, but today a car with much finer power plant and much more sturdy tires, one which is vastly superior in every detail of design and construction may be had for approximately $1,000. During that period the quality of the automobiles that were put on the market was constantly improved, the price just as constantly lowered, and still the money paid for each automobile paid not only for that car itself, but helped

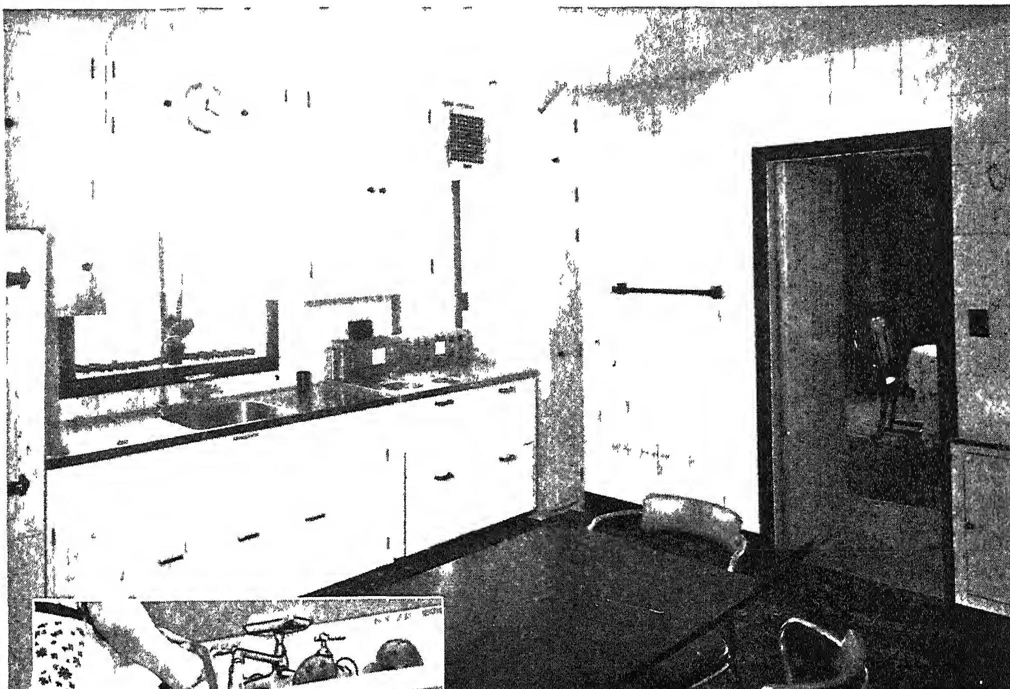
to build the vast factories and foundries in which the parts are made and the cars assembled and helped to defray all the costs of the machinery necessary to the manufacture of each new model And this has been accomplished in the face of rising prices for raw materials and constantly rising wages for labor

On the other hand the house which cost $6 000 in 1910 is not easy to build for $12,000 today It is true that we now demand a greater amount of expensive mechanical equipment than formerly, but in general the price of the dwelling has increased at just about the same rate as the cost of the raw materials which go into it and the labor which puts it together. The automobile industry has accomplished its miracle by making and marketing great quantities of motor cars and by a close organization of the whole designing, producing and selling systems from the raw materials at their source to the delivery of the car to the purchaser—by modern industrial methods. The men who urge the introduction of industrial methods into the production of houses have pointed out the inefficiencies of the present system and have brought out the fact that there is a great social need for inexpensive houses with modern equipment—scarcely one-third of the families in the United States today can afford the cheapest mechanically equipped new houses on the market. These men predict that the building industry of the future will adopt the ideas of the automobile builders; that the design of the house in structure, finish and mechanical equipment will evolve around a number of standard, easily assembled parts, which will be shipped to the job in exactly the proper quantities and there be put together like the parts of a picture puzzle so that when the house is finished not a single part will be left over. This process has been named prefabrication. The idea is engaging, and if mass production on this basis could really be established the cost of each dwelling could, without doubt, be materially reduced. There is no thought, however, that such a scheme would solve all of the problems of the present too-great cost of shelter, but it would certainly help.

Architecture has its artistic as well as its social side, but even here the development of industrial methods seems to have had an effect. Factory methods are the result of an interest in efficiency and that same interest seems to have influenced our taste in design. After insisting that the kitchen, in its equipment and the placement of that equipment, be organized in the minutest detail to save work, we discover that the appearances which characterize such efficiency are interesting to us, and that by proper designing they can be arranged to produce an architectural effect which is different from that the carpenter-builder sought but which is very satisfying to us. Our engineers and designers have not been content with producing automobiles capable of fine performance, they have striven to make them look responsive and speedy and have hit upon a new range of artistic appearance which again pleases us. Man wanted the machine tool to help him do his work. He got it and then discovered that the machine tool would not execute an elaborately carved chair leg as well as a craftsman with hand tools, and what he did most usually, was to keep his machine tool and re-design his chair leg. When it became evident that the precision of this new tool is most useful in executing clean, unembellished designs, man decided that he preferred designs of that sort—a comparison between the table lamps, the porch chairs and the automobiles of 25 years ago and those of today, or between the electric range here illustrated and an old cook stove will verify this. And so, whether we have prefabrication or not, there is some reason to believe that architecture will be influenced more and more by the machine tool and by standardized, factory-made parts.

There is, however, a good body of architectural opinion which is resisting

UP-TO-DATE KITCHEN APPLIANCES



Photos courtesy of General Electric Co.

A model kitchen with Imperial range and General Electric dishwasher.

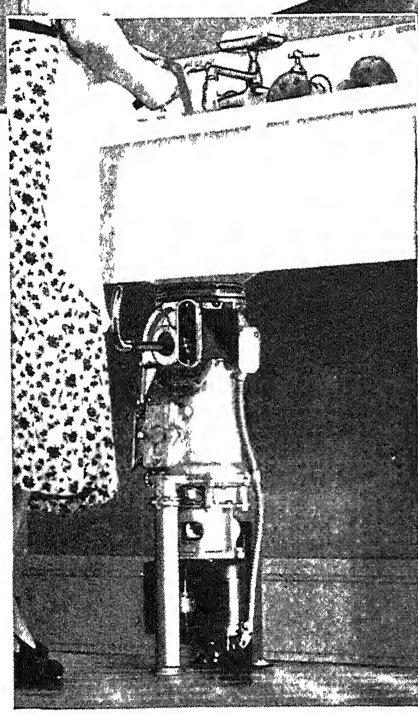
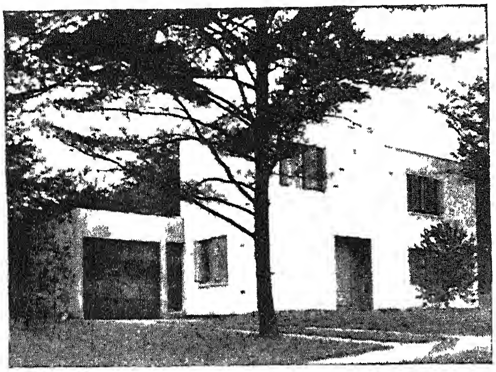
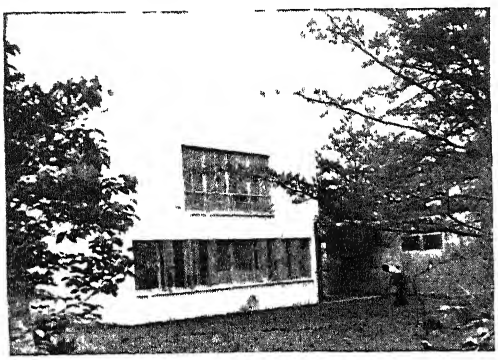


Fig 6 Waste disposal unit or garbage grinder, electrically driven, reduces all kinds of garbage, including bones, to a pulp that will pass down the drain and into the sewer.

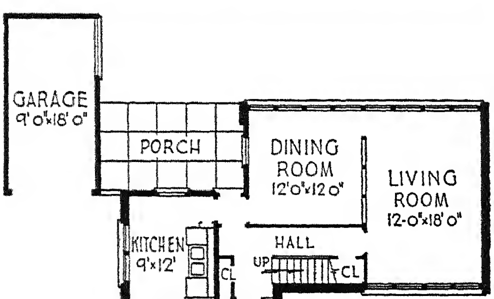
Enclosed form of the garbage grinder.



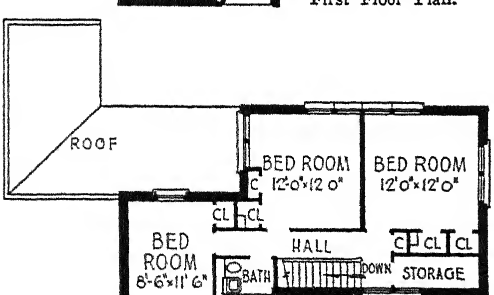
Front Elevation.



Garden Elevation.



First Floor Plan.



Second Floor Plan.

Courtesy The Architectural Forum.

Fig. 7. House at Washington, D. C., Berger Mfg. Co., sponsor, O. Y. Stonorov, architect.

this movement. The people as a whole, during pre-Revolutionary days, had a very clear idea of what a house should look like, but we have not yet settled that argument which began before the Civil War. Besides such houses as the one illustrated in Figure 7, which is definitely modern, in its appearance as well as in construction, equipment and layout, there were a great many houses built during 1935 which, in the details of their appearance, are patterned after the houses of Colonial days or those of medieval England or other architectural traditions of the past. The influences of the day are almost always to be found even there. It is not only that linoleum and bathrooms and breakfast nooks, and things of such distinctively modern appearance as oil furnaces and mechanical refrigerators will find their way into our houses, but, further, the designers who use the various traditions of the past are very likely to take as their inspiration some style which made use of plain surfaces and comparatively simple detail, even simplifying the traditional architectural ornaments—column capitals, window frames, etc.—to make them more adaptable to execution by machine tools and more compatible with the taste machine-made things have instilled in us.

The house we illustrate (Figure 7) is built with a number of rectangular steel frames, light enough to be handled without hoisting machinery, as units of the structure. These frames are three feet wide and tall enough to reach from floor to ceiling. They are simply bolted to one another and to the foundations, forming a rigid steel cage and the steel floor and roof beams are bolted to each wall unit. The frames which form the blank spaces are interchangeable with those containing openings, and the doors and windows are welded to the frames in the shop. The architect here was bound by the fact that the wall units were three feet wide. His living room, if he wanted to change the dimensions, would have to change in multiples of three feet. The

aim was to consider as equally important factors of a single problem the production methods of the shop which fabricated the steel, the system of assembly on the job and the design of the house itself, both from the standpoint of utility and convenience and that of appearance.

The interior walls attached to the frame are of a plaster building board. Immediately outside the frame are cork slabs three inches thick for insulation, then building paper and finally a single thickness of brick, whitewashed. There are many factory built wall boards which might have been attached to the frame outside the cork and then plastered, but the brick was chosen in this case, apparently because it conforms with a well established idea of what the wall of a house should look like, for certainly it is a reversion to the old methods of construction. The house which is shown in Figure 8 is more completely prefabricated in this matter. There is a steel frame, but here the interior walls are panels of a mineral compound which is sound-proof and covered with a non-fading, washable material, while the panels which form the exterior wall are of compressed cement and asbestos, integrally insulated. There is no need for a painter or a paperhanger to finish the job; even his work is done at the factory. Both of these houses have flat roofs. Throughout history until the 19th century, except in the dryest climates, houses have had sloping roofs, for shingles, slate and tiles are so laid that the steeper the slope of the roof the less chance there is for water to seep in. But in the 19th century sheet metal roofs and then roof coverings built up of tar and pitch were developed, so waterproof that only the slightest pitch for drainage is required.

But let us return to the plan of Figure 7. During the Civil War period it was still usual to have a barn for the carriages and the carriage horses at the back corner of the long narrow lot. With

Courtesy American Houses, Inc.

Fig. 8. A Prefabricated House.

the introduction of the automobile these barns became the first private garages, just as the livery stables became the first public garages. To this day the habit of putting the garage in a back corner of a long narrow lot persists. But the house we are discussing brings the garage forward and connects it with the house by means of a loggia, so that there is protection on the walk from the garage to the main hall of the house. Further, this arrangement eliminates a long driveway back to the garage and leaves the rear of the lot clear for garden treatment. In Civil War days the kitchen, too, was at the back of the house, and the parlor windows faced the street to impress the passer-by. But the motor truck and the automobile have made our streets busy, dusty places and our planning ideas have come to include a more or less private area for outdoor living, and so the kitchen has been brought to the front and the main rooms of the house look upon a secluded lawn or garden. The front porch upon which so many American families sat and talked across to the house next door seems definitely on its way to oblivion. Then, too, the windows of our new house are larger, again a contemporary development. The doctors have convinced us of the need for sanitary plumbing and have induced us to sleep with our windows open and they are now getting us to take an interest in sunlight for the benefit of our health. People in cold climates have always had small windows because windows permit the precious heat to escape. Today windows are better made and we have efficient heating systems. Thus even the people of northern Europe find that they can have large windows and still afford to pay the fuel bill.

The open wall between the living room and the dining room is another new feature. Men who today have the same standing in the community as did their grandfathers are likely to have smaller homes. Families, as statistics prove, are smaller and our scheme of living includes expensive things that were not thought of formerly. Moreover, as we have seen, a $6,000 house now costs $12,000. Faced with the necessity of designing very small houses, architects have adopted an old device to give a feeling of space to cramped quarters. They have done what very small houses all over the world have always done, left the spaces used for different living purposes as little divided from one another as possible. A dining room divided from the living room merely by a bookcase three feet high is common and there are many houses in which the library is treated in the same manner. The scheme permits the eye to travel about a greater space and gives the inhabitants of the room a less cramped feeling. Screens and curtains of various types, which can be drawn when privacy is desired in a certain area, are coming into use with this open type of planning—an idea long used by the Japanese.

The heating plant of this house is of special interest. A small enclosed unit in the kitchen contains not only the gas or oil furnace but a fan for circulating and equipment for conditioning the air, as well as a device for heating the water. Cold walls and floors are eliminated by having the used air return to the conditioner through ducts in the walls and floor framing of the house. And note that the bathroom is immediately above the kitchen so that all the mechanical equipment of the house is centralized, simplifying the installation problem considerably. The lack of space for the storage of food would have startled our grandmothers. In 1869 most families made their own bread and their own preserves and there was still a barrel of apples in the cellar, but we buy our food from day to day. There is the railroad and there is refrigeration in our homes, stores, refrigerator cars and cold storage plants; a telephone message to the grocer, in our cities and towns, will have his truck at our door within half an hour with two pounds of string beans and a

SOME HOUSES BEFORE THE REVOLUTION

Fig 1 Capen House (1683), Topsfield, Mass.

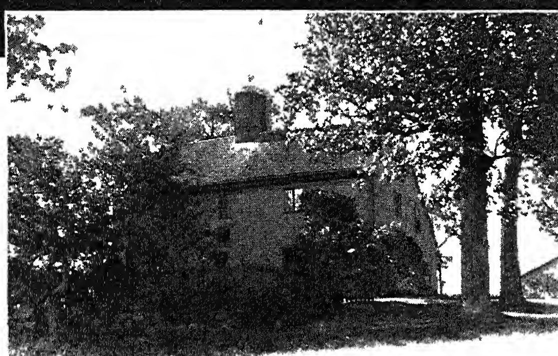


Fig 2 Rebecca Nurse House (1636), Danvers, Mass , home of one of the Salem witches.

Fig. 3. Ann Hathaway's Cottage (16th Century), Stratford-on-Avon, where Shakespeare courted her.

quart of strawberries on the coldest February day. The first vegetables of Spring which must have sent the colonists into ecstasies pass us unnoticed for we have had green things most of the winter. Yet, in spite of refrigeration which has largely replaced the older methods of food preservation, we retain our interest in breakfast bacon and marmalade—foods preserved today as of old.

The modern house, then, *is* different from those that went before it and all of the differences may be traced to our ways of living and of doing our work. There are few people who would choose to be without running water or refrigeration; but the debate as to just what a modern house should look like is as violent as ever. The tests of time and emergency may perhaps find some of our new methods and materials decidedly wanting, but if we retain the best of these new things and use them to the fullest extent it seems that we must expect our houses to *look* different from those made by different methods, out of different materials, by men of times past.

Illustrated below is a modern five-room house built for domesticity and comfortable living. Low-sweeping roof-lines make the home grow out of the ground. The service portion is accessible on one side, near the front, and all the space behind the house is available for a garden or game area. The one-story building consists of dining room, breakfast nook, living room, kitchen, two bedrooms, bathroom, and plenty of closet space throughout. The basement includes a recreation room, laundry room, heater and drying room, fruit room, and fuel or storage room. The house is planned for direct communication between the different parts, enabling the homemaker to cut her steps to the minimum.

Courtesy Better Homes & Gardens

MODERN FIVE-ROOM HOME

DIFFUSE MATTER IN INTERSTELLAR SPACE

by

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Professor of Astronomy and Geodesy, Cornell University

Illustrations Courtesy of Lowell Observatory, Flagstaff, Arizona

GALILEO was the first to confirm the speculations of the most gifted astronomers who preceded him, when he turned his telescope on the bright, nebulous areas of the Milky Way in Sagittarius and in Cygnus, and resolved such areas into myriads of faint stars.

Even casual observers have always noticed that the Milky Way is not of uniform brightness and that it is divided by a "great rift" extending from Cygnus to Centaurus. Sir William Herschel was, however, the first to delineate the form of the Milky Way and to determine minutely the apparent distribution of the stars which compose it. Nor did he rest satisfied with such a monumental achievement, but attempted to determine the space distribution of the stars, star clusters, and nebulæ which compose our galaxy, and to discover the relation of the nebulæ to the stars, as well as the meaning of the dark lanes and even darker holes often found in the midst of some of the richest star clouds which it contains.

When, as Sir William made ever better and larger telescopes with which to plumb the depths of space, he was able to resolve many of the objects listed as nebulæ in Messier's catalogue into stars, it was quite natural for him at first to conclude that all nebulæ were clusters of stars too far away and therefore too faint for him to see the individual stars.

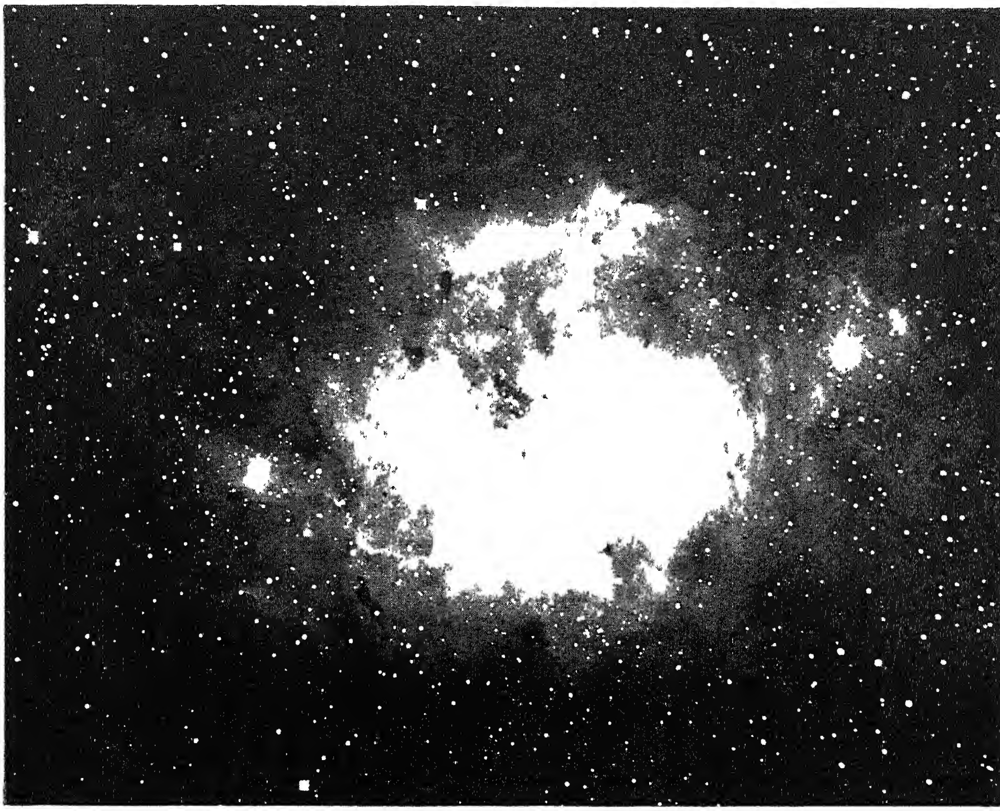
Probably most observers would have rested content with such an explanation, but not Sir William Herschel. He was too keen an observer not to notice that the more he increased the light-gathering power of his telescope, the less such a nebulosity as the one in the sword of Orion looked like the integrated light of stars too faint to see individually. If it were faint stars, some of the brighter ones should show in his largest telescope, while the background still looked nebulous, as was the case with the globular clusters. Also, close scrutiny seemed to reveal that involved in the nebula itself, were brilliant stars, some of which seemed partly veiled by the shining fluid of the nebula.

The advent of the discovery of the third law of spectrum analysis by Kirchhoff and Bunsen in 1859 made it possible to determine with certainty the nature of such shining gauze-like structures as the Great Nebula in Orion. It remains true, however, that Sir William Herschel had the first true insight into the nature of the diffuse, shining nebulæ as vast volumes of space filled with rare, shining fluid.

As Sir William Herschel constructed larger and larger telescopes, he at one time thought that his twenty-foot telescope would perform the miracle for at least most of the Milky Way, but when he beheld an almost clean-swept space in Scorpio, he exclaimed in amazement, "Hier ist wahrhaftig ein Loch im Himmel!"—much as a navigator sounding the ocean might say, when suddenly encountering one of the great ocean depths, "Here is a hole too deep to sound." These "holes in heaven," as Herschel often called them, continued to defy satisfactory explanation to the end of his life.

GREAT NEBULA IN ORION, N.G.C. 1976

The Great Nebula in Orion shows bright diffuse matter which is excited by the radiation of hot stars involved in it, with nearer clouds of dark diffuse matter which hide portions of the bright cloud beyond. The bright cloud and the hot stars which excite it to luminosity are at a distance of about six hundred light years.



The Lagoon Nebula in Sagittarius, N. G. C. 6523, is similar to the Great Nebula in Orion. In this case a number of small obscuring clouds of dark matter are seen, some of them being seen in projection on the brighter parts of the brighter clouds.

During the half century following his death suggestions were made that the dark lanes, the "Great Rift" and black holes in the Milky Way were due to vast, obscuring clouds of cosmic dust.

Barnard in his early life could not accept the view that obscuring clouds of cosmic dust were the cause of the patchy appearance of the Milky Way, but during the progress of his photographic survey of the Galaxy he became convinced that his early view was incorrect, and before he finished that valuable survey he had secured irrefutable evidence of the existence of such cosmic clouds.

Sir William Herschel was the first to conceive that many of those objects which we now call spiral nebulæ were distant galactic systems of stars separated from our own galactic system by a vast abyss of empty space. When we recall the almost total lack of knowledge of the distribution of the stars when Herschel began his work, we cannot but marvel at the vastness of the work which he and his sister accomplished in getting data which enabled him to give a first approximation to the form and extent of our galactic system and to obtain evidence that some of the objects which he studied were systems of stars outside our own galaxy.

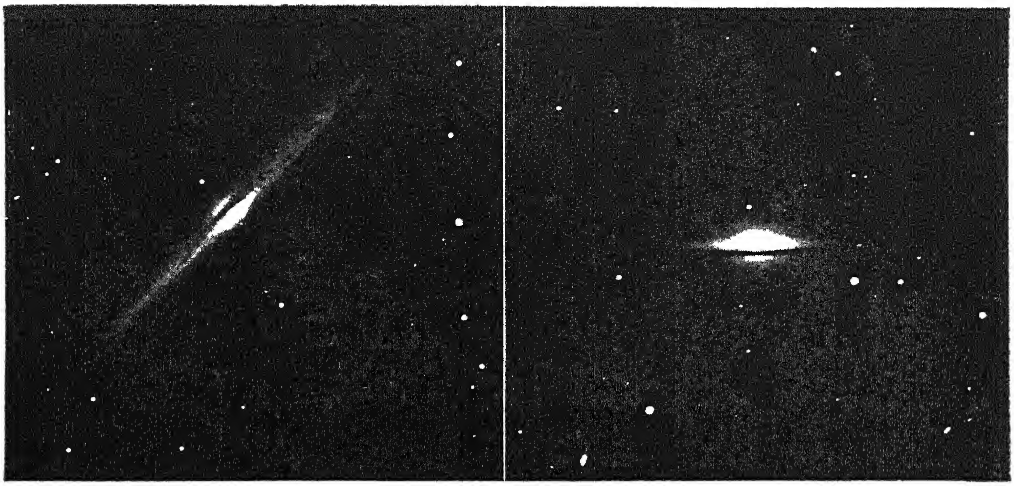
It is from studies of the distribution and apparent brightness of the extra-galactic systems of stars that we obtain data that enable us to determine the distribution, and something about the average density, of the cosmic dust which exists within our own galactic system.

Observations of those extra-galactic systems which we see on edge enables us to see how the cosmic dust is distributed with reference to the stars in those far-away systems.

TRIFID NEBULA IN SAGITTARIUS, N. G. C. 6514.

The brighter part of the nebula is partly obscured by nearer clouds of dark, diffuse matter, which divide it into three main parts, and other clouds of dark matter partly obscure the northern parts of the bright cloud.

Besides studies of the extra-galactic systems of stars which throw light on the general problem of the distribution of finely divided matter in our own galactic system, studies such as Barnard conducted are being carried forward by more powerful methods than were possible at the opening of the century. From photographic, photometric, and spectrographic work, carried on at the Harvard College, the Mount Wilson, the Lowell, and other observatories, much new data are being secured which will eventually lead to more accurate information as to the density-distribution of the great cosmic clouds which so far unfortunately hide from our view many of the richest regions of the Milky Way.



TWO FARAWAY GALAXIES WHICH PRESENT THEIR EDGES TO THE TERRESTRIAL OBSERVER

At left. A distant galactic system, N. G. C. 4565 in Comæ Berenicis, in which the plane of the system passes nearly through the earth and we therefore see a dark streak through the middle. The dark streak is due to obscuring clouds of diffuse material which lie in the plane of the Milky Way of this distant system. From spectroscopic studies of this spiral nebula it was first learned, by Dr. V. M. Slipher at the Lowell Observatory, that at least one galactic system rotates about an axis perpendicular to its plane.

At right. A distant galactic system, N. G. C. 4594 in Virgo, seen nearly on edge and therefore showing the obscuration caused by dark matter in the plane of the Milky Way of that distant galaxy. This system of stars is very far away and is receding from us at the rate of hundreds of miles per second as first determined by Dr. V. M. Slipher at the Lowell Observatory.

The bright central nucleus of our galactic system, which it is now generally agreed lies in the direction of Sagittarius, is largely hidden from our view by the interposing cosmic cloud which has its greatest dimension in the plane of our galaxy. Even where this cloud of dust and gas does not hide the stars, it dims them just as the sun and stars are dimmed when seen through the dust-laden atmosphere when rising and setting.

One of the objects for organizing and carrying on the observations made by large astronomical expeditions is to obtain vital information about the cosmic material in the region of our galactic system now being traversed by our solar system. These expeditions, which travel to those parts of the globe where various astronomical phenomena can best be observed, have explained much about the mechanics, nature and probable future of our universe.

Spectroscopic studies of the diffuse luminous nebulosities in which many star groups are involved reveal the nature of the material, whether finely divided particles or gas atoms excited by the radiations of hot stars. Thus, V. M. Slipher at the Lowell Observatory showed early in this century that the faint nebulosity in which the Pleiades are involved consists of finely divided particles in a vast cloud, which can be seen at distances of the order of four light years from the star which illuminates it.

As was intimated earlier in this chapter, the application of the newly discovered laws of spectrum analysis to the observed spectrum of the Great Nebula in Orion showed that it consists of rare luminous gas. This nebula and others of its kind are nothing more than local condensations in a vast cloud of ionized gas atoms which exists throughout all the space occupied

by our Milky Way system of stars. If not local condensations, such so-called gaseous nebulæ may be regions of the vast cosmic cloud of dust and gas in which certain of the gas atoms are excited to radiate visible light by the radiations of high-temperature stars.

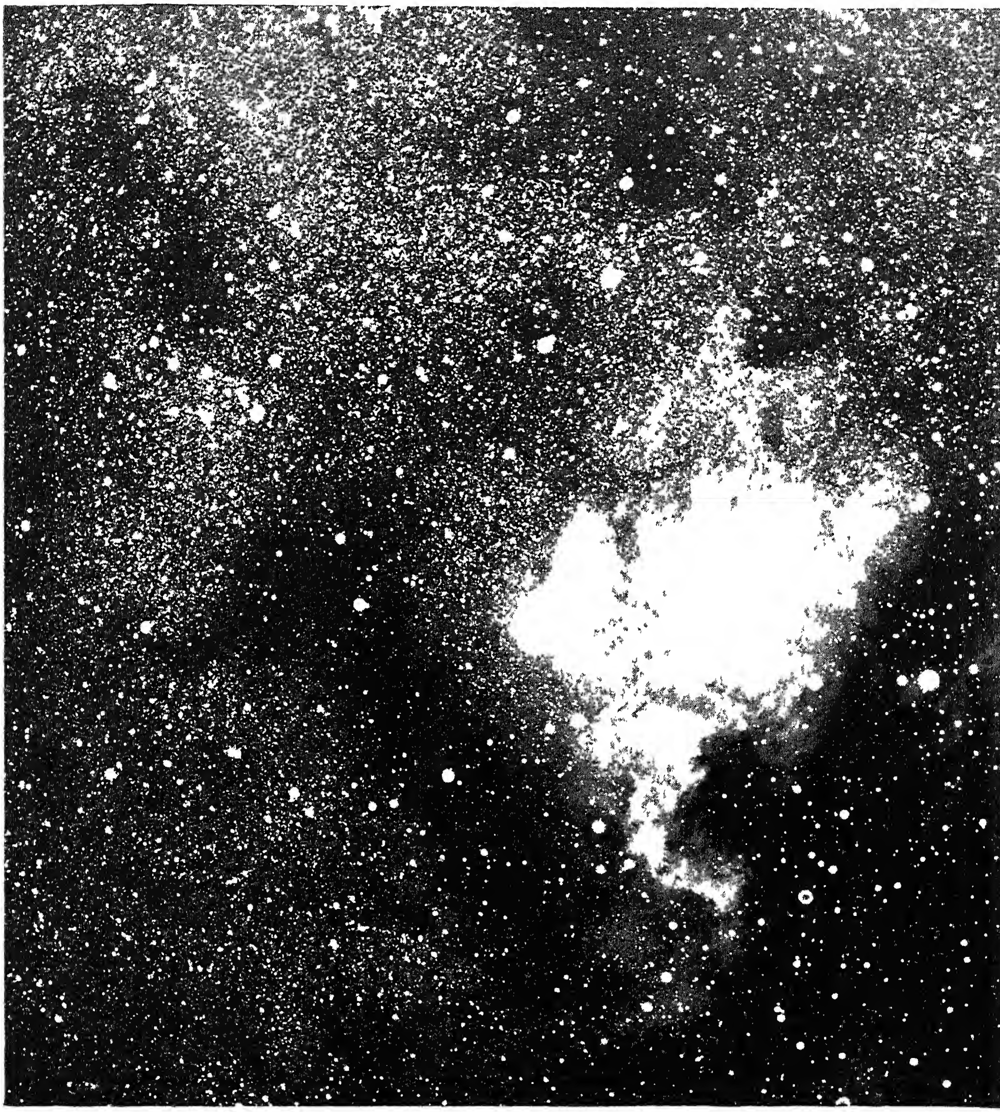
What is the nature of the evidence that the atoms of all substances exist diffused, as rare gas throughout interstellar space, denser near the plane of the Milky Way, and thinning out as we recede from that central plane?

The first evidence was secured by Hartmann, toward the turn of the century, but the most suggestive and penetrating early contribution was made by V. M. Slipher of the Lowell Observatory in 1909. Two tell-tale lines, known as H and K in the violet of the spectra of very hot stars, reveal the secret for ionized calcium atoms. Dr. Slipher noticed that for ten such stars in Scorpio, Ophiuchus, Perseus, and Orion the H and K lines were each double, one line of each pair giving the radial velocity of the star as determined by star lines due to other elements in the star, and the other line of each pair giving the same very slow motion as determined from each star. Dr. Slipher very cautiously advanced as a hypothesis: "It might then, for the present, be assumed that the calcium absorption has its origin in an interposing cloud covering at least certain extensive regions of the sky." At the same time he suggested that two lines called D lines, close together in the yellow of the spectrum and due to sodium, be investigated to see if the same "interposing cloud" contained sodium. Miss Heger at the Lick Observatory about a dozen years later confirmed the prediction made by Dr. Slipher for sodium. The D lines of sodium due to sodium in the interstellar gas have also been observed at other places, chiefly by J. S. Plaskett at the Dominion Astrophysical Observatory at Victoria, British Columbia. Struve at the Yerkes Observatory and others working elsewhere obtained evidence which still further strengthened the conclusion that rare ionized calcium exists all through interstellar space.

However, the most complete and convincing data, recently obtained, come from the Dominion Astrophysical Observatory, as one result of the extensive program of spectroscopic work being carried forward there. This work is so extensive and so complete that it not only establishes the presence of an all-pervading cloud of rare ionized calcium gas, but enables J. S. Plaskett and J. A. Pearce to determine from the data for such all-pervading calcium the rotation of our galactic system, thus confirming values of said rotation determined at the Harvard, Mount Wilson, and other observatories from studies based on observed stellar motions.

The author is quite happy to know that he contributed one small bit of evidence establishing the presence of this all-pervading interstellar calcium in connection with a spectroscopic binary star whose orbit and spectrum he investigated while at the Dominion Astrophysical Observatory during the summers of 1919 and 1920.

In the 1926 Bakerian Lecture before the Royal Society, Eddington discussed the constitution of the cosmic diffuse matter in our galactic system as derived from theoretical considerations based on the observational evidence from the bright and dark nebulæ, and upon the observed distribution and magnitudes of stellar motions in the system. This lecture gave a great stimulus to work in this field of cosmic physics and resulted in much of the advance made in the solution of the problem since that time. Eddington discussed the physical conditions to be expected in diffuse matter in interstellar space and showed the probability of uniform distribution except where condensations in this matter give rise to the diffuse nebulæ. He showed that there must exist every kind of matter which we find on earth and in the same relative abundance for the different elements as is found in the earth and stars. Eddington further showed that at the density found for this cosmic diffuse matter, the average density is so low that there would be less than one pound of material per hundred million cubic miles.



A region of the constellation Cygnus showing the North American Nebula and obscuring clouds of cosmic dust which in some places completely obscure the stars in one of the richest star strewn regions of the Milky Way.

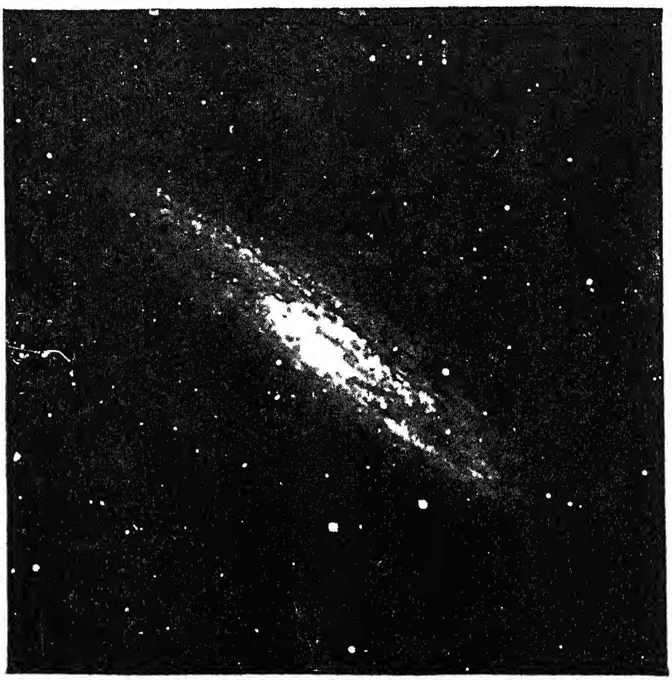
We will consider the densest matter we know in the chapter The White Dwarf Stars, but we are now considering the rarest matter we know, except perhaps the almost total lack of matter in intergalactic spaces. It might, therefore, be well to give illustrations which will convey some idea of the atomic population in matter as we know it and in the rare matter of which our cosmical studies bring us knowledge.

If a cubical box one inch on a side were full of air, such as we find at sea level, it would contain an order of about one hundred million times a million times a million atoms. If a small hole, which let out only one atom at a time, were made in the box, and a tiny imp counted the atoms coming out at the rate of one million per second, how long would it be before all the atoms of air had escaped and the inside of the box was a perfect

vacuum? Not one year, nor ten; not a century or even the whole extent of recorded history, nor even of man's existence on earth, but ten million years.

If, instead of air at normal atmospheric pressure at sea level and at normal temperature, we exhausted the air from the box to get the best vacuum we can produce, the imp would still have to count the atoms escaping at the rate of a million per second for ten years before the box would be empty. In the rare matter in interstellar space there is on the average about one atom per cubic inch.

For gas as rare as it is in the diffuse intergalactic matter the total radiation of the stars produces a molecular speed corresponding to temperatures of eighteen to twenty thousand degrees Fahrenheit above the absolute zero. At such temperatures nearly all the atoms have lost one or more of their normal complement of electrons. Such atoms are called ionized atoms. Singly ionized calcium atoms will be relatively few in number among all calcium atoms in the diffuse matter, as most of the calcium is doubly ionized or better, at such temperatures. Normal sodium atoms are relatively few in number, as are the singly ionized calcium atoms, but no other atoms are in sufficient abundance in states where they give lines in the accessible regions of the spectrum, so we do not get lines in the spectrum of the diffuse matter for any elements other than calcium and sodium.



THE SPIRAL NEBULA IN CETUS, N. G. C. 253.
The plane of the galaxy here is inclined to the line of sight by so small an angle that the obscuring clouds are seen.

In order to see the lines of calcium, there must be a depth of the interposing diffuse matter of at least six hundred light years, and for sodium the required depth is much greater still. In order, then, to see the lines of ionized calcium, we must have the spectrum of a star which is bright enough in the violet region, where the ionized calcium lines appear, to see them on the bright background of the star spectrum. The only stars, then, that are bright enough and hot enough to give sufficient light in the violet of their spectra to show the lines are stars of thousands of times the luminosity of the Sun. Only such stars are sufficiently bright for us to obtain their spectra at the enormous distances required to obtain enough absorption by the interposing ionized calcium to see its spectrum on the background of the stars' spectrum.

Much still remains to be learned about intergalactic matter and space. Astronomers are continually searching the skies with new and more powerful instruments in an effort to unlock the mysteries of the heavens. The ultra-violet spectrum, which astronomers rely on as their principal tool in such work, promises to reveal the secrets of many highly luminous stars. These in turn may throw more light on the distribution of matter in interstellar space.

CHEMURGY

New Riches Down on the Farm

by
WHEELER McMILLEN

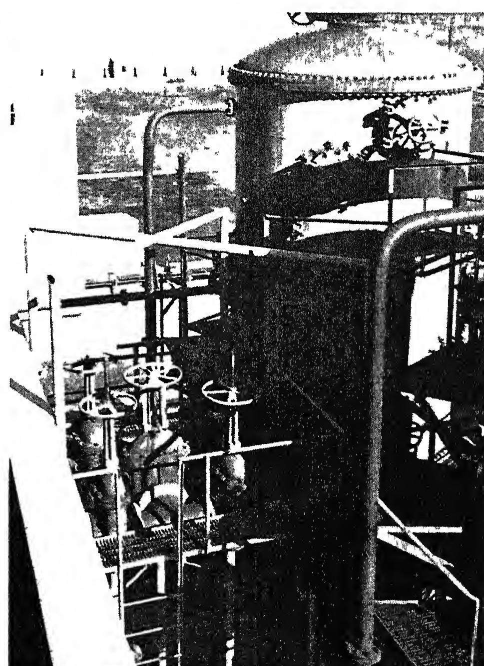
A FIELD of ripening oats in July makes a pretty picture The tall, slender stalks bow to the slightest breeze; a few long leaves reach out from the stalks. The sheathed grains clustering at the tips shake like green and gold bells. A few long leaves reach out from the stalks.

It is only the kernel, hidden within a tough outer hull, that is suitable for human oatmeal or rolled oats. When man has extracted and eaten the kernel and gathered the straw to bed down his livestock, has he made full use of the oat plant? For countless generations the answer to this question would have been "Yes." Now another story can be told, a story that illustrates strikingly how science searches out new riches from the soil, in the form of materials useful to industry.

A manufacturer of breakfast foods looked out one day upon the mountain of oat hulls that was rising near his factory. A small part could be ground up for livestock feed, but the value was trivial and the market small. The rest of the hulls were fit only to be tossed into the boiler fires; that is, unless a chemist could find some new use for them.

A chemist did. He found that oat hulls yield a chemical compound called furfural. At first there was no known use for furfural, but laboratory workers kept experi-

Weighing sample corncobs to be used in the manufacture of furfural. This product now serves for nylon, for lubricating oils and for cementing together hard particles to make abrasive surfaces.



Both photos, Quaker Oats Co

A distilling plant used for making furfural by the chemical treatment of corncobs and oat hulls These parts of the crop were almost valueless until chemurgists found ways of utilizing them.

menting with it until their curiosity began to pay dividends. They discovered that in the refinement of lubricating oils furfural would dissolve out the substances that made these oils gummy. Soon the petroleum industry was buying tank carloads of furfural.

Then some one found synthetic resin adhesives are even more adhesive when furfural is added. Modern grinding tools and abrasives are made by cementing millions of tiny particles of great hardness. They are made to stick together by adhesives that are tough and resistant to heat and water. Furfural now plays an important part in the cementing process. Furthermore, chemists have found that furfural can be turned into one of the materials necessary for the manufacture of nylon. A large new plant has been built at Niagara Falls for this purpose.

The oat straw is no longer used only to bed animals. It contains an important raw material called cellulose, and after chemical treatment this substance can be converted into fiberboard and various forms of paper. Large quantities of oat straws are now collected and sold for that purpose.

This story of the modern uses of the oat plant shows how science takes materials that used to be thrown away and creates useful products that add to man's wealth and promote his welfare. We give the name of chemurgy to such industrial uses of plant materials. The word chemurgy was coined in the twenties of the present century from the Egyptian root word *chem* and the Greek word *ergon*. Literally it means putting chemistry to work.

Chemistry — more specifically, organic chemistry — is indeed the key science in chemurgy. Organic chemistry has created a wide range of useful products — fuels, dyes, explosives, plastics, rayon and nylon, among others. Its raw materials are cellulose, proteins, starches, sugars and other natural componds — substances that are readily available in plant life. It is the organic chemist's endless search for such materials that has made the rise of chemurgy possible.

A few pioneers began to promote the idea of chemurgy in the 1920's, when farm surpluses in the United States were a national problem. They pointed out that nearly half the tonnage grown by farmers consisted of potential chemical raw materials, such as straws, stalks and culls (rejected parts of the crop), for which there were no commercial markets. These agricultural materials would be especially attractive to industry because they would be inexhaustible. It is a sad fact that nature either does not replace minerals that are consumed, or else replaces them at a rate that can not begin to keep pace with our consumption. Plant raw materials, on the contrary, are self-renewing. With many crops the entire production of a year may be consumed, except for seed, and then renewed by another year's growth.

Ecusta Paper Corp

Storing bales of fiber from flax straw, later to be used for cigarette paper. Fine stationery and Bible paper are also manufactured from the fiber.

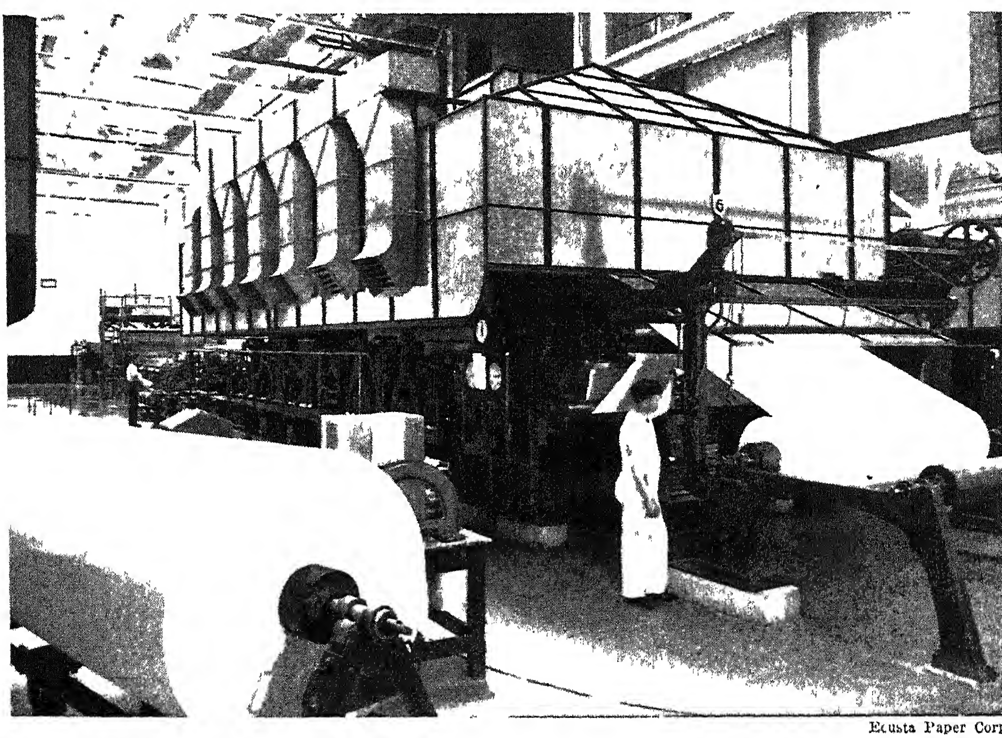
The idea of applying chemurgy on a wide scale gradually took root. In the spring of 1935 a number of men prominent in agriculture, industry and science were invited to attend a conference at Dearborn,

Michigan, in order to discuss the possibilities of chemurgy. As a result of this conference, the National Farm Chemurgic Council, Inc., was established, with headquarters at Columbus, Ohio. The council does no research directly but devotes its efforts to acting as a clearing house of information. It brings the subject of chemurgy to the attention of large numbers of people and it promotes support for public and private research.

Congress brought about a long forward step in chemurgic research in 1938. As an amendment to the agricultural act of that year, it provided for the establishment of four regional laboratories to be devoted entirely to finding new uses for farm products. These laboratories were set up at or near Philadelphia, New Orleans, Peoria and San Francisco. To each one was assigned a program of research in the crop generally grown in the nearest area. The laboratory buildings, costing $2,000,000 each, were completed and opened in 1940. Each laboratory was provided with space for erecting pilot-plant equipment, where new processes could be tested on a semicommercial scale.

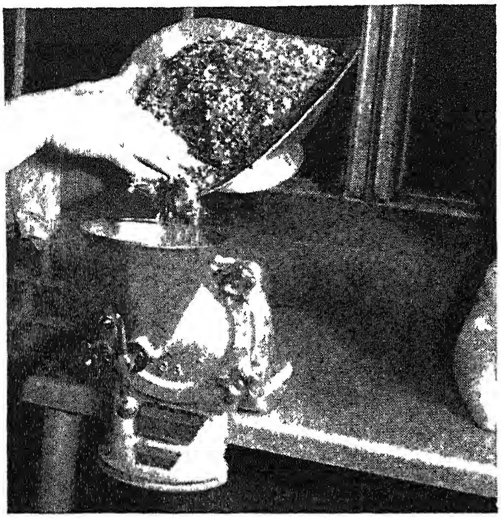
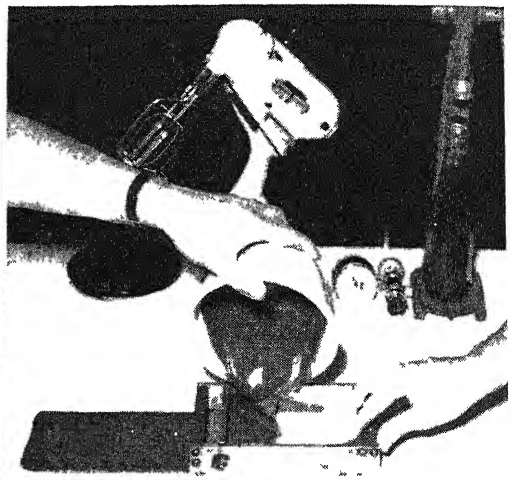
A number of state experiment stations and universities are now taking part in chemurgic research. So are many industrial laboratories. Nearly every large food-processing company has also become a chemical manufacturer in order to make the maximum use of the materials at hand. As for chemical companies, they have naturally made an intensive search for the raw materials supplied by agriculture. Regional research institutions in several areas have also turned their attention to the development of new industrial uses of agricultural resources. Among organizations of this kind are the Midwest Research Institution, at Kansas City, the Southern Research Institute, at Birmingham, the Texas Institute of Technology and Plant Industry, at Southern Methodist University, Dallas, and the Southwest Research Institute, San Antonio.

Chemurgy arose in the United States



Ecusta Paper Corp.

Cigarette paper, made from flax fiber, issuing from the end of a Fourdrinier paper-making machine.

Both photos, U S D A.

The left-hand photograph shows peanut shells being ground up for the production of Norceal, a substitute for cork in the linings of bottle caps. After the ground materials have been mixed with other ingredients, they are poured into sheets, as shown in the right-hand photograph; they set in this form. When the sheets have been cut to appropriate lengths, they are ready for shipment.

and has received by far its greatest development in that country. But there has been wide interest in the chemurgic idea elsewhere. The National Farm Chemurgic Council includes members from twenty-four nations; and farm chemurgic councils have been set up in other lands.

Chemurgy attacks the problem of finding new industrial uses for plant crops in three different ways. (1) It seeks new uses for the plants now commonly grown as crops. (2) It tries to find profitable uses for the wastes and residues of agriculture. (3) It is always on the search for new and more profitable crops.

New uses for old crops

Chemurgic research has made old crops more valuable by providing new industrial uses for them. Milo maize has long grown in Kansas, Oklahoma and Texas. It is a species of corn whose grain develops at the top of the plant where the corn carries its tassel. It has long been valued as a feed grain, but until recently it had no industrial market.

Chemurgic researchers in the corn products industries developed processes for making the grain into starch. A multimillion dollar plant for this purpose started operations at Corpus Christi, Texas, in 1949. The plant supplies a market for thousands of acres of Texas milo maize; it produces starch, dextrins, syrups and other products. Dextrose produced from milo maize is used in large quantities for the processing of cold rubber for automobile tires.

Profitable uses for agricultural wastes

The development of furfural is one illustration of how a waste farm material has been turned to profitable account. An even more interesting story, perhaps, tells how chemurgy found a new material for cigarette paper.

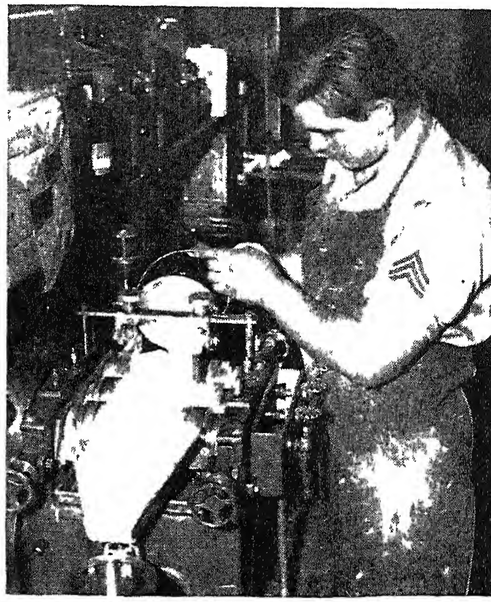
Until about the outbreak of World War II, nearly all the cigarette paper consumed in the United States was made by factories in France from old linen rags collected in Central Europe. The owner of one of the largest French factories was an American citizen; his customers were America's tobacco companies. Perhaps he saw that the second World War was coming. At any rate, several years before the outbreak of the war, he decided to bring his business to the United States.

But where would he find a suitable raw material for his paper? He knew he could

not count on linen rags, for linen is not so generally used in the United States as in Europe. After trying a number of materials and spending large sums in experiments, the manufacturer hit upon the idea of using straw from the American flax crop. Large acreages are planted to flax in the northern and western states. The crop is harvested, however, not for the fiber to make into linen (except for a few thousand acres in western Oregon), but for the seed, from which is pressed linseed oil, an ingredient in paints. The flax straw was considered worthless and in some areas worse than worthless, for the straw often had to be raked up and burned because it did not decompose readily in the ground.

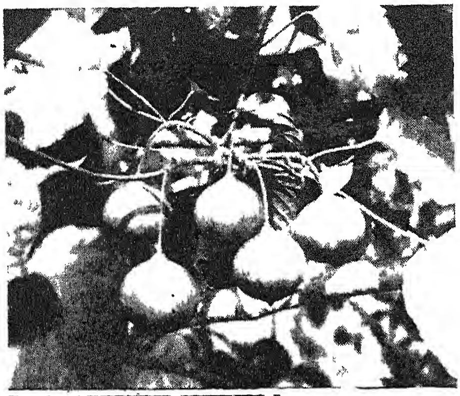
Our manufacturer found that an ideal raw material for cigarette paper could be produced by blending fibers from flax straw collected in two widely separated regions, southern Minnesota and southern California. The straw is harvested and processed into tow near the fields; then it is shipped to North Carolina. There a $10,000,000 factory makes it into paper, enough to wrap nearly every cigarette manufactured in the United States. The enterprise has now been greatly extended. Fine stationery, Bible paper and even paper for United States currency are now produced from the flax straw. New jobs, a wholly new market for a formerly wasted farm product and a domestic supply of several kinds of paper are products of this adventure in chemurgy.

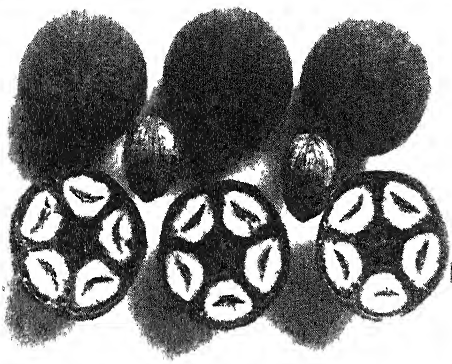
In some cases chemurgists have created important new substances from waste products. Rutin, a drug that is useful to people with high blood pressure, is being man-



Both photos, U S D A

The soybean is a most versatile plant; it serves as a nourishing food and it yields an amazing variety of industrial products, from plastics to printing inks. Above: a three-roller laboratory paint mill grinds paints in soybean oil. Below: rows of soybean plants stretch endlessly on a Minnesota farm.





Both photos, U S D A

Tung oil, a valuable ingredient of paints, is derived from the nuts of the tung tree. Above: a cluster of tung nuts; below: some cross sections.

ufactured from buckwheat leaves. Peanut hulls, or cornstalks, or sugar-cane bagasse (the part of the plant that remains after the juice has been extracted) can be made to yield Noreseal, a substitute for cork in the linings of bottle caps. A sirup from cull apples has taken the place of glycerin to a considerable extent as a material for keeping the tobacco in cigarettes moist and even-burning.

The search for new crops

The search for useful new crops is an important part of chemurgic research. In some cases these new crops replace old ones that, for one reason or another, are no longer profitable.

In the years preceding the great depression of the 1930's American farmers grew so much wheat and cotton that profitable markets could not be found. Because of the low prices farmers could not prosper, and they had to receive substantial help in the form of large government subsidies. Chemurgists believed that in many areas it would be well to introduce other crops, which would command a higher price than wheat or cotton and which would supply materials that the nation lacked, instead of adding to surpluses. They attacked the problem with all the resources of organic chemistry, plant-breeding and agricultural engineering. The result was the development of several alternate crops, which had hitherto not been particularly important in the United States or had never been introduced.

The most important of these crops is the soybean. This plant has been a staple food crop in China, particularly in Manchuria, for several thousand years; and as a matter of fact it was not unknown to America before the rise of chemurgy. Early in the nineteenth century it had been brought to the Western Hemisphere by sailing-ship captains, and it had flourished in a small way. But no one had found much use for the plant; it was grown mostly for hay and for hog pasture. Not until after 1920 did any one year see as much as 1,000,000 bushels harvested in the United States.

In the last year of the nineteenth century Amercian agricultural experiment stations began to look into the possible industrial uses of soybeans, and these experiments were continued in the first two decades of the twentieth century. It was shown that oil pressed from the soybean could be used for a variety of products. In the early twenties oil mills began to recognize the importance of soybean oil, and farmers planted more and more of the beans.

Chemurgists became fascinated by the soybean; they found it the most versatile crop known to science. An almost infinite variety of industrial products can be produced from soybean oil and meal. To meet the demand for these invaluable raw materials, more and more acres have been planted to soybeans; annual production has grown to something like 200,000,000 bush-

els a year. In Canada, too, the soybean has become an important crop.

The oil makes up one-fifth of the soybean, and more than twenty thousand tank carloads of it are separated every year. More than half the oil goes into cooking fats, about one-fifth into margarine and about one-twelfth into salad oils. The remainder is used for paints, lacquers, linoleum, oilcloth, window shades, printing inks, putty, insecticides, disinfectants and soap. The meal that remains after the oil is removed has become a foremost ingredient in livestock and poultry feeds. The meal is also used in the manufacture of industrial products like adhesives, textile fibers, waterproofing for textiles, waterproof glue, spreaders for insect sprays, finishing waxes, paper-sizing materials, and plastics.

The soybean has become increasingly important as a food. Among the products we now get wholly or in part from the soybean are baked beans, canned green beans, breakfast foods, candies, chocolate drinks, coffee substitutes, crackers, flakes, flavorings, flour, infant foods, macaroni products, milk substitutes and soups.

Thus, largely through the work of the chemurgist, the soybean has become a major crop in the United States and its cultivation has been steadily increasing. It is produced principally in the midwestern states. The fields in which it grows would otherwise have been planted to corn, wheat and other crops which in normal years might produce surpluses.

Tung oil is a valuable ingredient in paints and varnishes because of its drying properties. The United States had to import all its tung oil from China and Japan until the twentieth century, since the tung tree, from which the oil is derived, was unknown in the Western Hemisphere. In 1905 a few nuts were sent to America from China, and were planted at Brookville, Florida. Now, in Florida, Mississippi, Texas and other states along the Gulf Coast, tung orchards flourish on thousands of acres. Yet not nearly enough is grown to meet the demand.

Because supplies of tung oil were insufficient, chemists cast about for another substance that would do some of its work. Finding no natural oil that was satisfactory, they tried to see what they could do by changing the composition of known oils. They found that by eliminating water (H_2O) from the molecules of castor oil they could produce a substance that was nearly as good as tung oil for many purposes. The castor beans that yield the oil in question are now imported chiefly from Brazil and India. But tests have shown that the plant grows readily in much of the United States, especially in the area between the cotton and corn belts. It seems likely that the castor bean will become an important new crop in the United States before long.

Thus far we have dealt with the introduction into a country of crops that are well established elsewhere. In some cases

U S D A.

A guar plant. The seeds of the guar yield mannogalactin mucilage, a product that is mixed with paper pulp to produce a fine quality of paper.

C.I A A.

Bales of guayule being checked by the agent of a rubber company. Guayule yields natural rubber.

the "new" crops were new in the sense that they had not yet been cultivated anywhere on a commercial scale. As a matter of fact, we have hardly begun to tap the immense plant resources of the world. Well over 300,000 plant species have been identified by botanists. Yet man uses extensively not more than 2,000 species, and probably not more than 1,000 species are cultivated anywhere as crops.

The legume called guar (*Cyamopsis tetragonalaba*) was recently introduced to cultivation as a result of chemurgic research. Not long ago paper manufacturers decided that they could make better paper if a material called mannogalactan mucilage were mixed in the pulp. The paper would be more opaque and it would have better printing qualities. The only known source of the material was the carob bean, the product of a locust tree common in the Mediterranean regions. The total available supply, however, was much less than the industry required. Experts launched a search for some other plant that would yield the same product. It was found that guar, which is native to India, produces an abundant yield of a small seed from which the mannogalactan mucilage can be extracted. Efforts are now being made to establish guar as a crop in Texas.

In the effort to create a domestic rubber supply during World War II, experiments were made with two plants that had never been widely cultivated. One of these was the guayule, a shrub growing in the desert areas of southwestern United States and northern Mexico. It was found that the guayule can be cultivated and processed to yield natural rubber. However, since guayule rubber costs more than that obtained from the rubber tree (*Hevea brasiliensis*), the cultivation of the guayule shrub has not made extensive progress.

Another substitute for the rubber tree is a Russian species of dandelion, known as kok-sagyz. It is the roots of this plant that yield the latex from which rubber is made. Seeds were obtained from Russia and test plantings were made at various

Collecting seeds from kok-sagyz plants, in an experimental station of the United States Department of Agriculture, in Montana. Kok-sagyz, a

American state experiment stations. There were substantial yields of kok-sagyz in some of the northern stations; and extraction of the latex proved to be neither difficult nor costly. These tests were abandoned under wartime stress. The experimenters learned enough, however, to indicate that kok-sagyz might some day become a profitable crop.

Sometimes advances in processing methods open the way to establish new crops. Perhaps the finest of all natural fibers is ramie. It is several times stronger than cotton, silk, flax or hemp; it is stronger wet than dry; it gives off no lint; it dries quickly; it can be spun or woven with other fabrics. It can be cultivated wherever the ground does not freeze more than an inch or so deep. It is planted from roots, and a single planting will produce stalks for four to seven years.

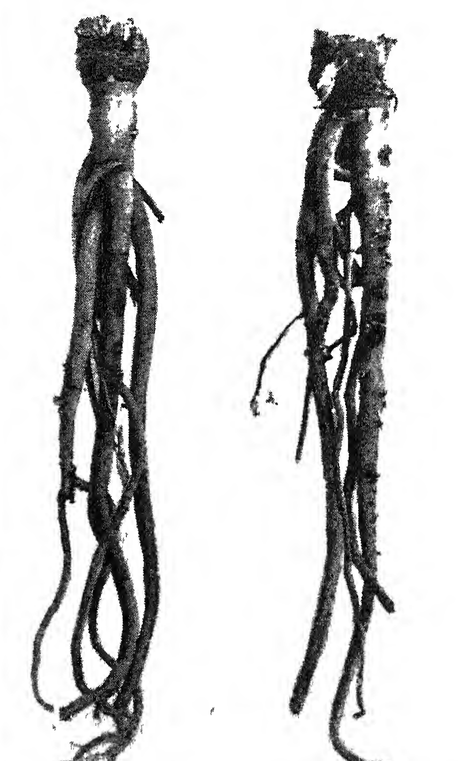
Ramie has been known for centuries in southern Asia, but its production has been limited because only by painstaking hand methods could the fibers be removed from the stalks, and a sticky, hard gummy substance removed from the fibers. Since hand labor in the United States is altogether too expensive for such work, ramie made no headway there. But now there are improved mechanical devices for processing the fibers. As this is written several thousand acres of ramie are growing in Florida and Texas, and other southern states have experimental areas. It seems likely that, when the new process is perfected, ramie will become thoroughly established in the lower south.

Effects of chemurgy

There is no doubt that chemurgy has taken its place as a powerful industrial factor. What will its effects be?

For one thing, it will tend to decentralize

Russian species of dandelion, yields rubber. Since the plant is hardy and fertile, it offers great promise as a bountiful source of supply.



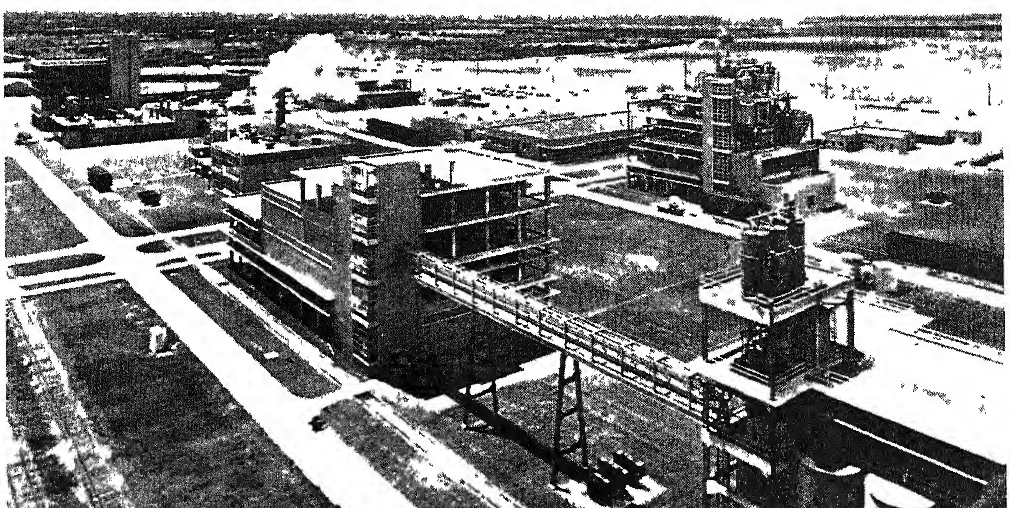
Both photos, U S D.A

Kok-sagyz roots. The latex from which rubber is made is obtained by milling (grinding) the roots. The process involved is not particularly costly.

industry. There is a growing tendency to erect processing factories near the farms where their raw materials grow. As more and more of these materials are made available for industry, processing plants will become more widely distributed. Since manufacturing costs are lower in rural communities, this development will benefit industry. It will benefit the workers, since they will be able to live amid more pleasant surroundings than in the crowded and smoky areas of big cities. It will also be a boon to the communities in which plant-processing enterprises are located; it will make more wealth available for efficient health departments and good schools and roads.

From the viewpoint of national defense, the development of new industrial products from agricultural crops will be helpful to the United States and Canada and other nations which have to import certain necessary materials from distant lands. If a war should interrupt production abroad or suspend shipping, the supply of imported materials would soon be exhausted and a serious crisis would develop. When the Japanese overran Malaya and the East Indies in 1942, they cut off the chief source of rubber supply for the Allies. Fortunately the United States carried through a successful synthetic-rubber program; otherwise the rubber shortage might well have undermined the entire war effort.

Chemurgy, then, will serve as a shield in time of war. It will also actively promote peace by raising the standards of have-not countries. It will enable farmers to make more effective use of the crops that now flourish in their fields, and to add new, profitable crops. It will make possible the variety of production that is the best guarantee of prosperity. Thereby it will help to do away with the poverty and discontent that have always been a fertile breeding ground for wars.



Corn Products Sales Co

The Bluebonnet plant of the Corn Products Refining Company at Corpus Christi, Texas. In many cases, processing plants like these are erected near the farms where the raw materials grow. Manufacturing costs are comparatively low in the communities in which such plants are located. Workers find pleasant homes there; they can bring up their children far from the crowds and the smoke of big cities.

LIFE'S CHOICE OF THE BEST

Spontaneous Favoritism for Whatever Serves the Individual Good or the Common Weal

HAS NATURE A SENSE OF MORALITY?

THE idea that natural selection has created the forms and powers of the living world is seen to be absurd. That is clear gain for our century, compared with the latter half of the nineteenth, when the great majority of those who thought at all saw no way out of the mechanical theory which, we now see, explains why what is not is not, but does not explain how what is came to be. Judged on the plane of philosophy, natural selection is condemned; the problem of *origin*, which it purported to answer, is not even alluded to in the theory of Darwin and Dr. Wallace.

And now the way is clear for our study of natural selection in general, and its significance in the study of life. Over-production, heredity and variation are facts of the living world, and therefore, as we have seen, natural selection must necessarily occur. But further, we need recognize only heredity and variation in order to see that many other kinds of selection, obviously possible, may produce notable results so long as variations occur; selection chooses among them, and heredity perpetuates them.

When the selection is simply the destruction of those who are least able to survive in the conditions, we call it "natural selection", and the phrase is always misused when it is applied in any other way. Yet natural selection may be infinitely various in its consequences, according to the particular conditions which preside over it, and we realize that all sorts of other selective agencies are possible, each capable of affecting the future composition of a species in any degree.

Thus, as Darwin taught, individuals may choose one another as mates, or individuals of the same sex may fight one another for the possession of a member of the opposite sex Plainly selection is at work in such cases. It is not natural selection; it has nothing to do with available food-supply, nor the struggle for life, and it has or may have special consequences of its own. Darwin gave it the name of sexual selection.

Again, the fertility of individuals, plants or animals may differ. Any two of them may be equal, perhaps, in the struggle for life, or one of them may barely survive in the struggle; but that one may be fertile, and the individual which, as an individual, is an easy winner in the struggle for life may be infertile or scarcely fertile The individual may thus be selected by natural selection, only to be condemned by what may be called reproductive selection; and we can readily see how the action of this mode of selection may affect the composition and destiny of a species.

Yet again, man may so modify the conditions of his own life, or those of the life of any living species he takes an interest in, that those who would have survived are rejected, and vice versa. This may often occur in artificial selection, as practiced by the human breeder, of pigs or bees or peas, or anything else But, further, man may quite unknowingly and unintentionally subvert the normal conditions of selection in his own species, so that the survivors are just those who, in natural conditions and circumstances, would not have survived.

This is, by a quibble — that everything is nature — natural selection still; but we may quite usefully recognize its peculiarity, from our point of view, and call it *un*natural or reversed selection. And, on the other hand, the eugenists are now setting out to practise a form of selection, for ideal ends established by themselves, quite apart from the automatic and impartial attitude of nature, and this has been called human or eugenic selection.

And, again, when Professor Weismann, some years ago, was very hard pressed to explain certain facts on his theory of the germ-plasm, he invented what he called germinal selection, a kind of struggle for life between germ-cells, or between different constituents of the "germ-plasm" in the formation of germ-cells from it. Not much is heard of germinal selection nowadays, but the theory is conceivable, and its invention and its inventor will always be part of the history of the science of life.

In altruistic selection the individual chosen as an organ of the race

All the forms of selection hitherto named have dealt with individuals, but there are other possibilities. No theory of selection that simply had regard to the life of the individual could explain the evolution of, say, the breast of the mammalian mother, or of any other structure which serves its individual possessor not at all. There has been not merely the "struggle for life", with what we call natural selection as its result, but also "a struggle for the life of others", with the result which we may call altruistic selection — *i.e.*, other-ish selection. Here the individual is formed and chosen not for itself alone, any more than, say, the hand or the heart is formed for itself alone. The individual is shaped and chosen as an organ of the race. Here is a great idea, not unseen by Darwin himself, which it was left to Henry Drummond to state as it deserved to be stated.

And, lastly, we learn from a multitude of instances that what is really, in a sense, a form of natural selection — as altruistic selection is too, no doubt — occurs, not with reference to individuals, but rather with reference to groups or societies.

Thus we find in studying societies of insects or of men, the unit of selection, the unit judged and taken or left, may be not the individual, any more than any particular organ of the individual, by itself, but the society or community *as a whole*. Thus a nation may be selected and another rejected, or a society of bees, whose social character is high, as against another swarm in which the bees are comparatively improvident, for insect societies vary just like human societies.

In the case of mankind, innumerable social influences — such as, say, the type of marriage, whether monogamous or polygamous — may determine the "viability" or the "survival-value" of the society. And thus it may be chosen or extinguished, not in reference to its individuals as individuals, but as a social whole. Where the unit of selection is thus a society, we must plainly call the process social selection.

That completes our first survey of the subject, and we begin to see its interest and difficulty and complexity. For within the society upon which social selection is being practiced, in its struggle for life with other societies, there are also at work natural selection, and sexual selection, and the other forms of selection, which may be mutually complementary, or merely supplementary, or, on the other hand, may neutralize or antagonize one another. And at every change in the environment, whether of climate or diet, or the presence or absence of other species, whether the introduction of new ideas, or new inventions, the balance and interplay of all these modes of selection are altered — perhaps radically and momentously, by a change in conditions apparently so trivial that no one can even name it. No wonder that the interpretation of the history of man, his races and nations and civilizations is as difficult as past attempts at such interpretations demonstrate!

Let us put our forms of selection together in an ordered list, and then attempt to state the main propositions which must form the basis of all future thinking upon this subject. Here is the list, and though it might be added to if we chose, it includes all the important forms of selection:

INTERIOR OF A NEST OF ACTIVE WASPS

The wasp furnishes an interesting example of social organization, each individual in the nest working for the general good. In this photograph, by Mr. J. J. Ward, the wasps seen on the upper tiers of the comb are workers. On the lower tier are two young queens and a male wasp.

Group I

1. Natural Selection
2. Sexual Selection
3. Reproductive Selection
4. Germinal Selection

Group II

1. Altruistic Selection
2. Social Selection
3. Artificial Selection
4. Reversed or Dysgenic Selection
5. Eugenic Selection

In this list are included typical and admitted forms of selection, together with others which may some day be discarded, arranged primarily for convenience of study, into a first group where the unit of selection is the individual, and a second group where the unit is more than an individual, or where the selective agent is itself a group of individuals. It is not pretended that the classification is perfect, but it may be offered as a tentative attempt.

Natural selection a fight to show fitness between men and disease, man and man

But, first, there is one general question which must be disposed of. Man is a moral being, and has a moral point of view. If the forms of selection are the judges of the forms of life, man is himself the judge of the forms of selection. So he must be; and the first condition of just judgment is to understand the facts of the case; above all, the fact that selection is not, in itself, moral or immoral. Thus natural selection is the survival of the fittest, and though the fittest may be the best, as man judges, so may they just as possibly be the worst. It all depends upon the conditions. The conditions are the real determiners, for they decide what the selective process shall result in. It is merely the machinery.

The name of "survival-value" may be given to the quality or combination of qualities in virtue of which individuals, species, societies survive. Thus the murderous sting of the worker-bee, the bosom of the mammalian mother, the "toxin" of the microbe of consumption, alike are instances of this so-called survival-value. The first comes under social selection, for it helps not the bee but the bee-hive; the second under the heading of altruistic selection; and the third under the heading of natural selection.

Plainly our moral judgment upon selective processes, our approval or disapproval, must depend not merely upon the particular type of process, but upon its results.

GROUP I

1. *Natural Selection*. Only one point needs to be added to our previous discussion: natural selection, in the case of man, notably takes the form of a struggle for the life of the individual, and for the life of the human race as a whole, against the humble forms of life which depend, for their existence, upon the production of disease in man. This aspect of natural selection, dealing as it does with matters which come so near to "men's business and bosoms", requires and will receive special discussion according to the various species — tubercle bacillus, malaria parasite, etc., with whom the fight is waged.

The fight is not to be fought that it may weed out the unfit

There is, however, a second aspect to this contest, which has been very largely discussed. Not only is the selective struggle between man and his enemy, but it is also between the individual man who resists more strongly and him who resists less so. The selective process may act inside the species. Exposure to, say, the tubercle bacillus may mean that the most susceptible members of successive generations of man are weeded out, they and their possibility of producing offspring like them, so that a population will be evolved which is immune to the attacks of the bacillus, and thus the disease will be conquered.

The same argument has been applied to the use of alcohol, the assertion being that we must allow natural selection — as these writers fantastically call the influence of the slum or the gin-palace — to weed out the susceptible, until we produce a race, the members of which are proof against the dangers of alcohol.

This line of argument is here noted, as it must be, on account of the wide credence which it has gained among the half-informed, and because one or two distinguished writers, now belonging, however, rather to the past than the present, have formally urged the theory of natural selection against all attempts to fight alcoholism, tuberculosis and similar enemies of mankind. Elsewhere in the course of this work it will be shown in what comprehensive detail the facts recorded by the first-hand science of experiment and observation are in direct opposition to these speculators.

Darwin's theory that sexual selection adds the beautiful to the useful

2. *Sexual Selection.* The theory of sexual selection was set forth at length by Darwin, in his second book, "The Descent of Man," with great wealth of observation and argument. The theory was well worth framing, and has immensely stimulated thought and research during the fifty years since its publication, but no modern biologist ranks it as high as popular opinion still does. Darwin's theory was practically an application to the animal world of arguments from the case of man, just as his theory of natural selection was an application to the living world in general of the idea of artificial selection as already practised by man himself.

The theory was introduced by Darwin as a supplement and complement to the theory of natural selection. If natural selection were universal and constant in its action, and if nothing else were at work, every feature and characteristic of every living being ought to be useful. If it has been made by the struggle for life, it must have some survival value. We can thus understand how natural selection would favor the feathers and the eyes of the bird, by which it is helped to fly and mark its prey. But why should those feathers be not only useful but often beautiful? Nay, more, why should those feathers be sometimes so extravagantly beautiful, so large and unwieldy, that instead of favoring the possessor they must handicap him in the struggle for life?

On every hand, but perhaps chiefly among the birds, we find features which natural selection cannot explain, and which natural rejection — to call it what it really is — should have rejected. But there they are. Darwin's theory of sexual selection came to the rescue.

The failure of Darwin's illustrations to apply to half the world

He supposed that the wonderful markings and plumage, or the ravishing voices, of male birds are the result of selection by the females, who choose the suitor with the finest suit, or the serenader with the sweetest serenade. Such a process, assuming any constant standard of taste among the female birds, would plainly lead to the accentuation in the race of those characteristics which they persistently selected, and which would tend to be transmitted, and thus fixed in the race, by the mates they chose. Doubtless sexual selection may be imagined to take other forms, as when a number of males, say bulls, fight for the possession of a female, and thus pugnacity and strength and persistence are selected, and tend to be fixed in the race.

There can be no doubt at all that time has not been kind to this famous theory of Darwin. It cannot apply to plants, yet plants may occasionally, or perhaps rather oftener, vie with the beauty of animals. As an explanation of the evolution of features not purely useful — and therefore inexplicable by natural selection — sexual selection is thus irrelevant to half the world of life at the very least; and whatever explanation serves for the beauty, the not useful beauty, the "art for art's sake", of plants may serve for animals also.

Again, many features not useful, often very beautiful, and sometimes evidently disadvantageous, are found in living species where sexual selection is impossible, or where reproduction is asexual. Yet again we lack evidence to show that female birds possess the mental and æsthetic development and fastidious discrimination which the theory of sexual selection as outlined by Darwin involves.

The later experiments that do not reinforce but weaken Darwin's argument

Lastly, there is the fatal objection that, taking the world of life as a whole, the rule is that all adults become parents, whereas sexual selection can be operative only if certain kinds of individuals are chosen for parenthood and others are rejected. If there is no selection at all, since all become parents, there is no "sexual selection". To this brief summary of negative criticism may be appended the further observation that, in the last few years, the experimental breeding carried out by the Mendelians has gone a very long way to demonstrate how the color and plumage, for instance, of birds is transmitted, and what laws govern the formation of such characteristics in the first place. The positive facts thus obtained are quite incompatible with the theory of sexual selection, and require a wholly different interpretation.

We hinted that probably Darwin was led to his theory of sexual selection through argument by analogy from the case of mankind. That should remind us that to reject the theory of sexual selection, at any rate as of substantial importance in the evolution of the animal world, is by no means to deny its importance for mankind. On the contrary, every year's inquiry strengthens the view that sexual selection must be of the most tremendous importance in the case of mankind. Men and women *do* have the likes and dislikes with which Darwin credited birds. Only a proportion of men and women become parents, and there are demonstrable differences, on the average, between the parents and the non-parents.

Sexual selection in mankind, as regards beauty, for instance, is unquestionable, and must constantly tend to prevent a lowering of the standard of facial beauty. This selection is most conspicuously practised by men, exactly inverting what Darwin supposed in the case of birds, and the contrast is completed when we observe that woman steals and dons the plumage of the male bird in order to please the male of her species.

Careful and prolonged inquiry by Professor Karl Pearson has seemed to show, also, that married couples on the average notably resemble one another in eye-color, in stature and many other characteristics. This suggests not only that sexual selection exists among mankind, but that the tendency is for us to select our like — not to select our opposite, as popular theory supposes.

The sexual selection practised by mankind inapplicable to rest of animal world

To this mating of like with like, Professor Pearson has given the name of homogamy — *i.e.*, like-marriage; and it is one of the many reasons, derived from modern research, why sexual selection increases its importance in the estimate of modern science so far as man is concerned; while its inapplicability to the animal world in any large degree becomes more and more evident. Here we leave the theory, then, merely noting that while it almost passes out of biology, the science of life in general, it must be of vital importance for the new science of eugenics.

The limitations that apply both to natural and sexual selection

3. *Reproductive Selection.* We begin to realize that the evolution of a species does not depend, in the last resort, either upon natural selection or upon sexual selection, and cannot do so. Natural selection selects or rejects individuals, and thus largely explains the presence and the absence in any adult generation of the more fit and the less fit, respectively, from among those who were born to bid for life in that generation. But while natural selection explains, obviously, why some live and others die, it can have no bearing upon the race, it cannot affect the evolution of a species, unless we assume that the survivors become parents. If they do not become parents, their personal selection and survival have no bearing on the future composition and characteristics of the species. Just so, sexual selection, as such, merely explains who mate and who do not mate, as natural selection explains who survive and who do not survive.

However, here again sexual selection obviously has no influence upon evolution of the race unless we assume that mating means parenthood. More than that, the mating which results from sexual selection must be superior in fertility to that which does not, if evolution is to be affected. If the mating which results from sexual selection is habitually sterile, or produces, say, only a few offspring, while the mating of individuals who are, so to speak, "left over", is more fertile, then selective mating may be impotent as regards evolution.

The course of evolution determined not by selection or mating but by parenthood

Plainly, then, if any process of selection is to affect the race, and so explain or condition the course of its evolution, it must result in offspring. And thus we see that the whole theory of natural selection, with that of sexual selection, assumes a superior fertility on the part of the selected; and we begin to appreciate the idea of reproductive selection. Not survival, not mating, but parenthood determines the course of evolution. From and by what individuals, having what characteristics, *however selected*, is the species recruited? That is the whole question so far as its evolution by selection is concerned.

The comparative study of fertility rates thus becomes of immense biological importance. We require to study and number and compare the seeds or fruits or embryos — the offspring, in short — of all manner of animals and plants, so as to ascertain the types of individuals that are most fertile, which is a huge task in itself, and then to ascertain the particular types of matings that are most fertile. The last word is, necessarily, always with fertility or reproductive selection. It is not enough for nature, or the gardener, or the eugenist to select the kinds of individuals that are best adapted, or most beautiful, or most worthy. That is the first step, but it leads nowhere as regards the making or modification of any species unless the individuals selected are fertile — nay, more, unless their fertility be so great as to overwhelm that of the unselected stocks with which they may be set in competition.

The importance of these questions has only lately begun to be seen, but it is evident enough when once it is stated. In a word, any and every kind of selection that occurs in the living world must be compatible with fertility, and must maintain its compatibility with fertility if it is to affect evolution in any positive direction.

4. *Germinal Selection.* This theory of Weismann's belongs, as we have said, to the history of biology and must be named, but no more is now necessary.

GROUP II

1. *Altruistic Selection.* Clear thinking, accurate naming and lucid analysis ever proclaim themselves in the long run. The controversy that began with the publication of the "Origin of Species" did not conduce to these most desirable processes, never more urgently required than then.

Not until many years had passed was it possible for a thinker here, and another there, quietly to survey the facts and weigh the new ideas without any bias at all. Meanwhile there appeared the most horrible phenomenon in the history of human thought, which based upon the theory of natural selection a declaration that mercy and love and pity are "the morality of slaves"; that only the great principle of "each for himself, and the devil take the hindmost" — a perfectly accurate paraphrase of natural selection — can exalt a race, and that the final verdict of knowledge had gone forth to this foul effect. Such, in its naked horror, is the essential teaching (together with much that is fine and precious) of Nietzsche, and its substance was none other than this: that in order to become superman, man must become a devil.

There is nothing in the history of thought that resembles this ghastly application of Darwinism; and little more ironical than that it should have involved the name and the theory of the patient thinker, who hated fighting and controversy and the public platform, and loved his garden and his home and his children, and who expressly repudiated, in the "Ascent of Man" that Nietzschean application of his views.

The answer to this terrible creed was stated by the late Professor Henry Drummond, in 1894, in his "Ascent of Man". Written as it was with a confessedly religious intent, and by one whose first-hand acquaintance with the subject was small, Drummond's book received little acknowledgment from men of science, whose experiences in this direction had perhaps scarcely been encouraging. The book was before its time, as we may quickly perceive if we look at the grotesquely materialistic literature which passed for the best and most advanced biological thought of the end of the nineteenth century. All that kind of thing has died a natural death, though there is an occasional attempt to galvanize its corpse; and we may begin to see how scientific in substance was Drummond's contribution to the theory of organic evolution.

The struggle for life as qualified by the struggle for the life of others

The "struggle for life", which was all that the smaller followers of Darwin could see, does include and is constantly transcended by what Drummond accurately described as the struggle for the life of others. Far more than half the facts of the living world come indisputably under this head, if we will only look at them. The very name of the mammalia, the highest family of animals, at the very head of which man himself stands, gives the lie to Nietzscheanism and justifies the teaching of Drummond.

The struggle for the life of others, more particularly parental and still more particularly maternal, may doubtless be included under natural selection from one point of view. If a mother's love, to choose its supreme example, has survival-value — for her offspring — they will be "fitter", thanks to her. Yet only stupidity or bias can fail to see the measureless moral and practical distinction between the struggle and the selection thus effected and the typical struggle for life. In this new case, one individual struggles for the life of another, and the other survives not in virtue of its own merit but because another has struggled, sacrificed, possibly died for it. The facts may sound sentimental, or may be stated mawkishly or cantingly, but they are just as much facts, say, of the tigress and her whelps as are her terrible teeth and claws; and their evolutionary interpretation and their evolutionary consequences are likewise obvious and unquestionable.

Care for others is a law of nature which asserts the morality of nature

The materialists had tried to pitchfork morality out of nature by the theory of selection and the struggle for life; and the issue of the argument, on the ground chosen by them and waged by their own weapons, has been to demonstrate and establish morality securely in the heart of nature, from which no "higher criticism" of ancient literature, nor any shock of other discovery, can ever dislodge it. We find that altruism is a law of nature. Morality, this absurd invention of the priests, say the Nietzscheans, interferes most seriously with the operation of natural selection, which is the only means of giving us the superman.

To this argument, however, the reply is that natural selection, in the particular form of it which can only be called altruistic selection, selects morality. It selects whatever serves life, such as jaws and claws; but as love serves life supremely, and serves the highest forms of life the most, natural selection has had no choice but to select love, and to reject the loveless, also. Men ask the origin of good and evil; in this double method, the struggle for life (the life of self), and the struggle for the life of others, we see the biological statement of the answer to that old question. But all this is a matter so momentous for science and for religion that we can do no more than thus introduce it now.

2. *Social Selection.* Mr. Benjamin Kidd has done good service to the theory of selection by showing that, among the higher types of life in especial, the unit selected, as having survival-value, is not the individual at all, but some group, larger or smaller, of individuals who form an interdependent whole, "fit" or "unfit", as the case may be.

We can readily see how complete is the transition from natural selection, "each for himself", through the rudest and most transient forms of family life, involving, at least for short periods, what we have called altruistic selection; thence through the selection as entire units of large patriarchal families, if it be man we are considering, or of social groups among the lower animals, up to the cases where entire societies form units and struggle for life among themselves apart from and without any immediate dependence upon the individual forms of struggle and selection that are taking place within them. We may begin to imagine the significance of social selection if we consider a struggle, perhaps in war, between a highly organized nation, whose individuals may be, as individuals, mediocre, and another made of fine individuals but not united into a strong social unit. The verdict will be given in terms not of individual but of social selection, even though the result may be that inferior individuals survive. Thus a civilized but degenerate race may conquer in war another nation whose members are not degenerate, but who have not constructed such "social civilization" as results in a standing army, torpedoes, or such-like engines of progress.

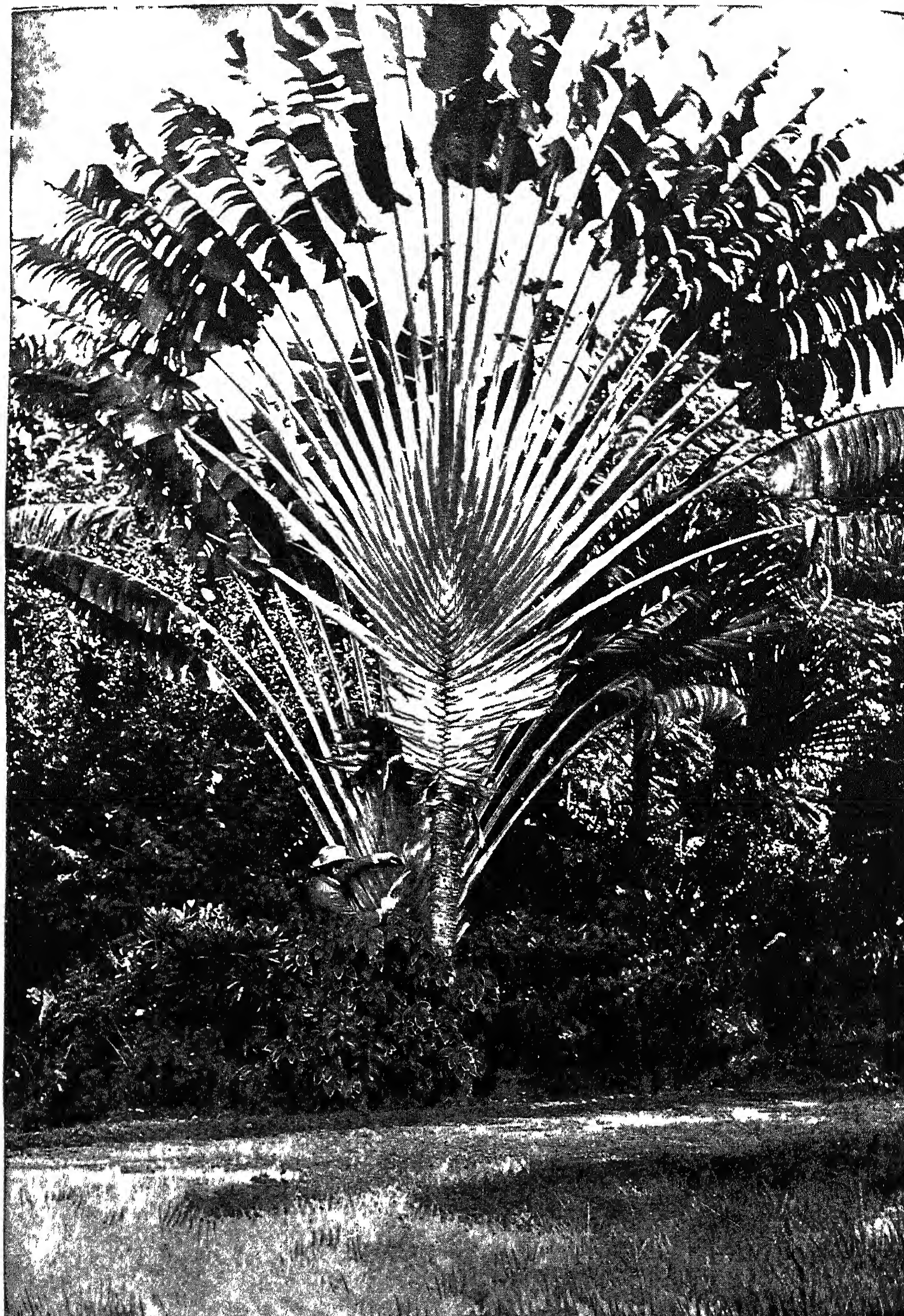
3. *Artificial Selection.* We come now to the three forms of selection that conclude our list, and are distinguished as being set in motion by man. Artificial selection nowadays includes not only the art of the gardener, the agriculturist, the stock-raiser, and so on, but also the experimental breeding practised by Mendelians and others for the gaining of knowledge only. One point alone needs mention under this head. It is that the method of artificial selection, when deliberately employed along the lines of natural selection with the object of trying to produce those changes in the form of species with which natural selection is credited, *always fail.* Such experiments begin as if they were going to succeed, but a point is soon reached when the steady selection of individuals that vary in the desired direction fails to advance the race any further along it. These experiments markedly contrast, by their failure, with the success in the formation and fixation of new types which follows artificial selection upon Mendelian lines, as we shall see.

4. *Reversed* or *Unnatural Selection.* This is frequently practised by man upon himself. It could doubtless be practised also upon other forms of life, but as there would be no possible object in such a process, man naturally avoids breeding from the worst or least desirable, except in his own case. To this process the name of *Dysgenic Selection* has been given, to contrast with

5. *Eugenic Selection*, which is the application to mankind of the Darwinian principle of selection for parenthood.

Such, in outline, is the modern fruit of the idea of selection which Darwin and Dr. Wallace introduced into the science of life.

A TREE AS WATER-FACTORY AND FILTER



THE TRAVELER'S TREE IN JAVA POURING FORTH, THROUGH AN INCISION IN THE STEM, A JET OF PURE WATER WHICH IT HAS ITSELF PRODUCED

THE ENERGY OF PLANTS

The Wonderful Sun-Drawn Rush of Life Through All the Earth's Eager and Irresistible Growths

PLANT PRODUCTS THAT BEGGAR GOLD

EVERYONE who has eyes to see has noticed the surprising energy of plants great and small. They exert this energy in a variety of ways — sometimes by direct mechanical and material effort, sometimes by subtle forms of leverage and the use of the wedge, sometimes by rather mysterious processes of attraction and repulsion, sometimes by chemical change.

Instances of all these are common, indeed, it may be said universal, but some, at any rate, may perhaps be best observed in their rarer and more peculiar forms. An example that has much interested travelers may be seen in many parts of Java, where a plant is used for practical purposes as a fountain. The stem is cut at a point several feet off the ground, and from the severed pipes pours almost continuously during the growing period, a jet of the purest water.

You may see such a plant-fountain in tiny form in many other plants, a blade of wheat, for example, but the energy is only enough to raise occasional drops of water. It is still rather a puzzle to botanists how this force is exerted, for the force is enormous. A watery fluid has to be pumped to the top of the tree against the natural and universal force of gravity. This could not be done by what is known as "capillary attraction" — that is, the force by which water is attracted from one atom to the next, irrespective of up and down, as when blotting-paper or a lump of sugar is dipped into a fluid. But attraction of this sort could not account for the upward flow of the sap except in a very minor degree, nor for the energy that is found.

The reason may lie partly in the "turgidity" of the successive cells out of which a plant is formed. The cells, we know, have a capacity, in itself rather inexplicable, of growing turgid — that is, swelling and exerting pressure all round. Such pressure may be very violent and, by quite understandable mechanical devices or processes of growth, only find its way upward, not downward, as the exploded powder in the cartridge set in a raised barrel.

But this theory is little more than finding a new name for an inexplicable thing. It rather suggests the presence of an undiscovered cause than explains with sufficient precision a probable cause. A more certain force is the familiar behavior of liquids, known in science as "osmosis", by which liquids in neighbor cells have a tendency to pass one into the other, the thinner liquid passing the more rapidly of the two through the intervening membrane. But not all these suggestions quite account for the attracting power of the pump which carries sap at an astounding rate up to the remotest leaves in a great tree.

One of the earliest experiments to test this force was with a vine. The stem was cut in the spring, when the vital force began to become active. On the cut stem a tube was fitted in a particular manner, and mercury introduced at the end. The force of the rising sap astonished even the experimenter, for it was found to equal the pressure of an atmosphere and a half. A simpler experiment is to tie a bladder tightly over the cut stump. If the tree is at all vigorous the pressure of the sap will be enough to burst the bladder.

How many tons of water are thus raised even within the confines of a small garden becomes a sum of vast magnitude. This activity is a part of the energy of life, that inexplicable and final wonder; but you may see the presence of an active force even when a part of the plant — especially, of course, the seed or its equivalent — is severed from the parent. It is a suggestive thought that the wheat-fields in autumn or the garden in spring are quivering with the emergence of an energy which in some unseen way seems involved in the very mystery of life itself.

The astounding force working irresistibly through soft and delicate plants

It requires no subtle or delicate experiment to test the astounding force which plants exert in the course of growth The soft and delicate rootlets make their way as surely as if they had intellect and instruments to the parts of the soil where moisture is to be found. As the roots swell they will force up tons of earth or rock. The stem as it thrusts upward will shatter stones to fragments, it will wrench thick iron into fantastic shapes, and finally tower upward according to the irresistible law of its being.

This power is hardly less conspicuous in the tender plants than in the stouter trees. Watch the slender spikes of crocus, daffodil or snowdrop pushing up to

> "Hail fair summer with their lifted spear."

They take little heed of clod or stone, but rise straight and true, the inward force too strong for the outward resistance. These things are worthy of wonder and admiration, yet the supreme wonder is the purely physiological and chemical energy in plants.

On the transformations which go on within plants the whole world entirely depends. Without the laboratory work which plants perpetually practise all life would at once cease. Earth, air, light and water are useless for providing the substance of life to animals, but they are not useless to plants, which alone have the secret of transforming them into the substances of which plants consist, and upon which men and other live things feed.

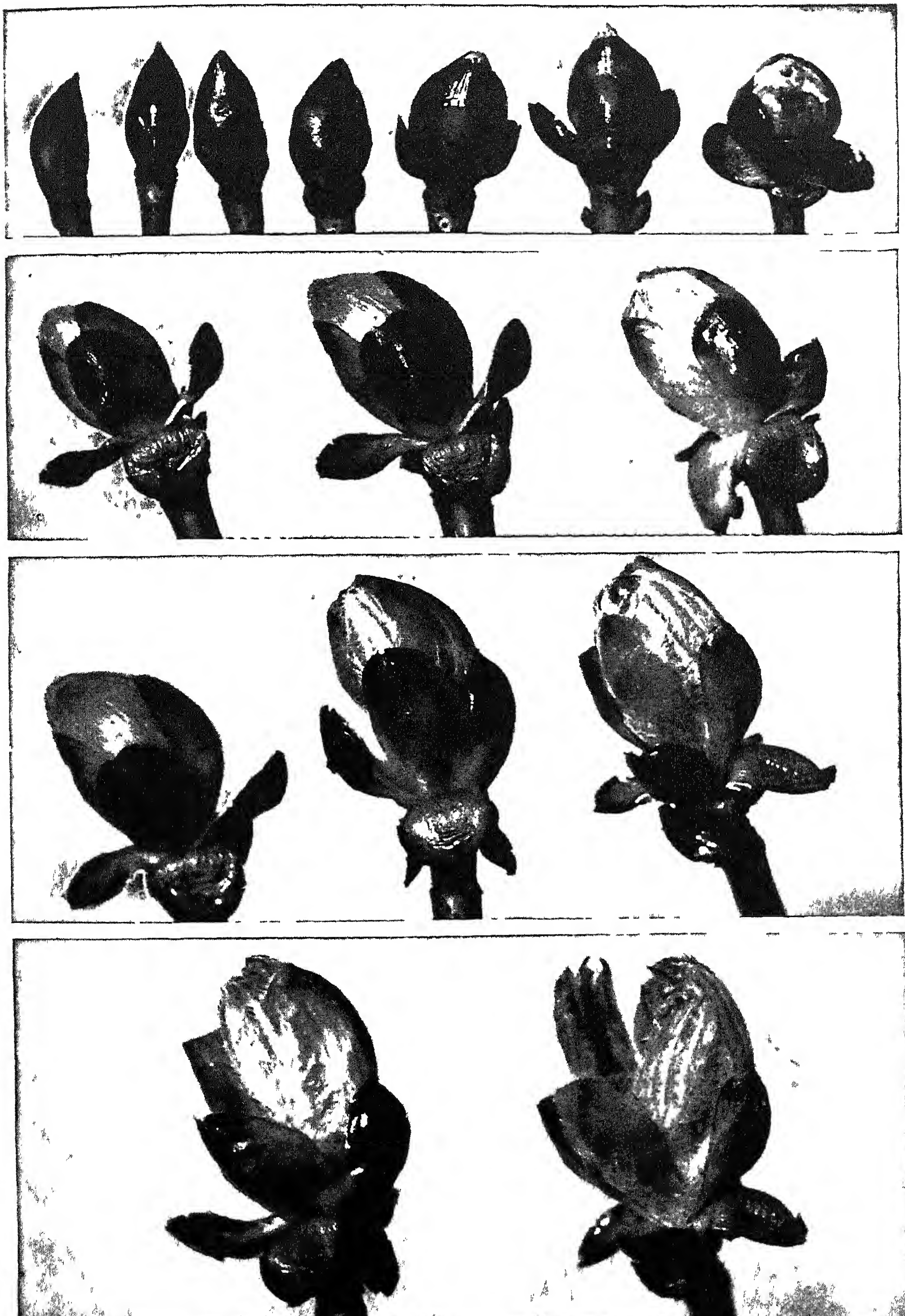
The analysis of dead things deserted for a study of the secrets of life

The chemists begin to spend less time proportionately on analyzing and splitting up into their parts the dead things which lie about the world. Less and less do they argue in the old way that because such and such things are formed in such and such a combination, therefore certain other things must happen. It is seen that to this kind of knowledge there is an end, and that out of it, immeasurably valuable though it is and will be, can never issue the real secrets of life Therefore, the men of science are advancing to the consideration of chemical changes in their relation to living things. They do not leave out the living spark, but examine and analyze under conditions of life.

In the growth of a plant is the ultimate secret. Tennyson spoke more prophetically than people even of his time understood when he made his quaint and much-quoted verse about the "flower in the crannied wall". If this could be understood, "root and all, branch and all", we should at least begin to understand what man is in a scientific as well as a mystic sense.

A very great deal is known about the chemical power of plants. The first thing to grasp is that every simple thing we eat — sweet or sour or bitter — is manufactured by plants out of substances which, like the chameleon, "feed on light and air", and on earth. There is no food whatever that is not, in the first instance, so made; so the study of this manufactory is one of the most elemental. The manufacture in the bodies of animals of one substance into another is secondary and much less wonderful. Meat and milk are much less remote from the grass out of which they are made than grass is remote from the sunlight it is said to "bottle".

The beginning of the miracle may be pointed out as the first tinge of green in the seed-leaf. This green color is the outward and visible sign that these qualities in nature which lie beyond our use are actually being turned into the very stuff of life.



A series of photographs of the development of a bud shows a remarkable strain and energy of purpose. The photographs on this page, by J. J. Ward, represent a horse-chestnut as it unfolds.

Without the aid of what may be called this chemical miracle we should all be in a waste of earth and air and water with not an atom to eat nor a drop to drink. And why or from what inward impetus the change began we do not — perhaps we may not — know, but nothing in the march of human intellect is more noteworthy than the precise and particular knowledge of the course of these changes. How, is a question that men of science can answer with a thoroughness that the men even of a hundred years ago would have held almost miraculous. Why, and whence, and whither, and wherefore, are some of the questions which overstep the kingdom of science and the wit of man.

How plants manufacture the food supply of all the world

We must therefore now only consider the "how"; and the story is not less full of wonder and interest because it must be told to some degree in words which do not carry an air of interest on their face. If there is one thing in the world of supreme importance among chemical substances, it is carbon; and it is in the production or manufacture of carbon that the supreme utility of plants consists. They are the only converters of the element that is in one sense at the basis of all the food supply of the world.

This conversion into a substance fit for the food of animals goes on in the various processes of growth. Plants are energetic very much in the sense that animals are energetic, except that they do not, as a rule, move about. There are examples of moving plants and bits of plants, about which Francis Darwin has, in the twentieth century, made some interesting experiments. But these are exceptions. For the most part the activity of plants is within themselves. Like animals they breathe in and breathe out. They have mouths. They eat and digest, but they eat not compound and solid substances, but largely the elements out of which air and water are composed, in addition, of course, to a quantity of mineral substances from the soil, changing each and all of these into food for animals.

The breathing of plants as men breathe and also by exhaling pure oxygen

It is not necessary now to describe all these processes of growth You can see them in the most simple experiments. For example, if you put a plant into colored water, you may watch the water, still retaining its color, running up the little roots. You see that it is taken in, but you have to infer the further fact that the hydrogen and oxygen out of which it is composed are separated and used to make the substance of the plant.

Again, you may easily see a plant breathe out. Take any evergreen leaves — laurel leaves are the best — and place them in water in a strong light. Within a short time numerous little air-bubbles will appear. They are the breath of the plant, composed, it is probable, of pure oxygen, that wonderful gas without which no man can live even for a few minutes. "The life-giving gas" is its name in some languages. Now, human beings, when they breathe, use the oxygen, and breathe out that part of the air which is poisonous to them, carbon dioxide. They never breathe out pure oxygen, as do the laurel leaves.

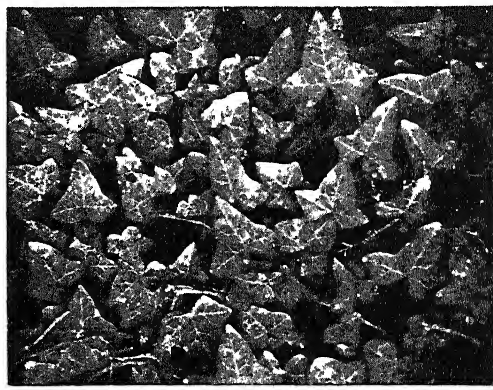
It is, however, necessary to remember that plants breathe in exactly the same way as men, as well as in this way which is peculiar to themselves. But the manufacturing process, about which we are now concerned, is chiefly associated with this habit of breathing out oxygen. What a plant can do, and no other natural agency can do, is to take in this more or less poisonous gas, carbon dioxide, which is found in most air, to separate the carbon, and employ it for building their tissue.

But this act of manufacture on which the world depends can only be done — except in rare cases, which are not properly exceptions — under the aid of the sun. When the light of the sun, whether direct or indirect, falls on a plant, there is formed a green substance called "chlorophyll", a word simply meaning in the original Greek "green leaf". This green and slightly sticky substance, which in spring paints our world with the color of health, is to plants what blood is to animals.

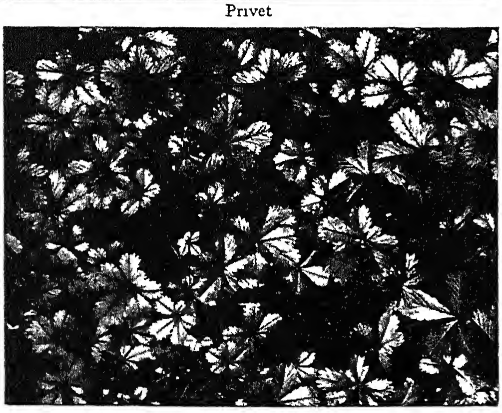
It is, indeed, more. Whenever this is present, and only when present, is the manufacture of carbon active. The chlorophyll is the fire which runs the factory; or we may say, perhaps more accurately, that the sun is the furnace and the chlorophyll the electricity, which the furnace creates for carrying out the work in hand and moving the machinery.

In a very short, rough summary, the whole process may be expressed thus:

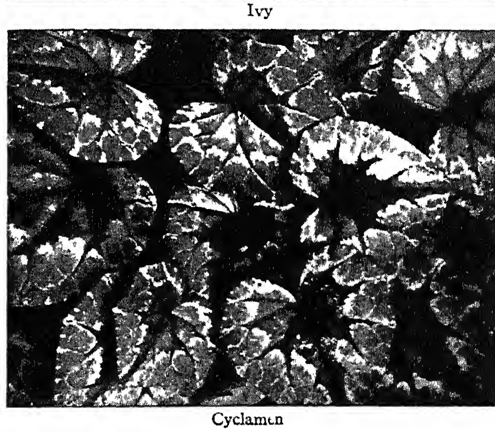
Privet



Ivy



Creeping cinquefoil



Cyclamen

THE GREED OF PLANTS FOR SUNLIGHT — FOUR EXAMPLES OF LEAF MOSAIC

the roots of plants take up a number of minerals from the earth, and a supply of oxygen and hydrogen from the water, as well as a small amount of carbon dioxide, which is soluble in water; the leaves perform the work of breathing in carbon dioxide, and within themselves, helped by the sun through the agency of this mysterious chlorophyll they breath away the oxygen, separating it from the carbon, which is passed down the plant, providing the chief material for the food of the world.

All this could scarcely be done unless the leaves or furnaces possessed a host of special qualities over and above this secret of changing and breaking up minerals. They must be thin and large and possessed of the power of reaching to the sunlight. Even in an elm tree, bearing thousands upon thousands of leaves arranged apparently in a haphazard mass, you will find that an enormous proportion are cunningly arranged to avoid shade and seek light.

Again in some trees you will find the leaves of a shoot making a mosaic pattern so perfect that not a hundredth part of the leaves is obscured, though they are nearly touching one another. When you consider the vigor of a great tree in early summer, each leaf at work transmuting all that it absorbs into a substance more precious than gold, you will see the tree under a new light, as a factory working at full time with an energy scarcely to be calculated in figures.

The making of starch and sugar in plants and the storing of energy

A great part of all this energy goes in several great divisions of plants into the work of concentrating the precious materials—the hydrogen and oxygen and nitrogen and carbon—into material needed either for the next generation of the plant (that is, in the seed), or into food for next season's growth, as in the potato or carrot. In wheat, almost all the grain consists of starch. When the outer husks are taken off the grain, and the almost invisible germ of the new plant is removed, almost all the rest is starch. This is taken by man from the would-be plant of next year to provide what we call the "staff of life".

The factory also turns out sugar at a good rate. Sugar is found in many parts of different plants — from raisins, for example, and from manna, but the most important supply is, for men, in beet-root and in sugar cane. In the East Indies, no less than 17 per cent of the sugar cane is pure sugar and of this sugar 42 per cent consists of carbon. In the sugar-beet the sugar is meant to supply food and vigor for the plant in its second year. Different plants, of course, turn out different products. The nut is largely composed of fats and oils which also consist of the element of carbon.

The energy stored up in a Brazil nut, for example, may be seen by changing the oil into heat. Cut a part of the kernel into a pyramidal shape and put a match to it. The resulting heat or light is no more than another form of the energy of the oil which springs from the energy of the sun working on the elements of which our world is composed.

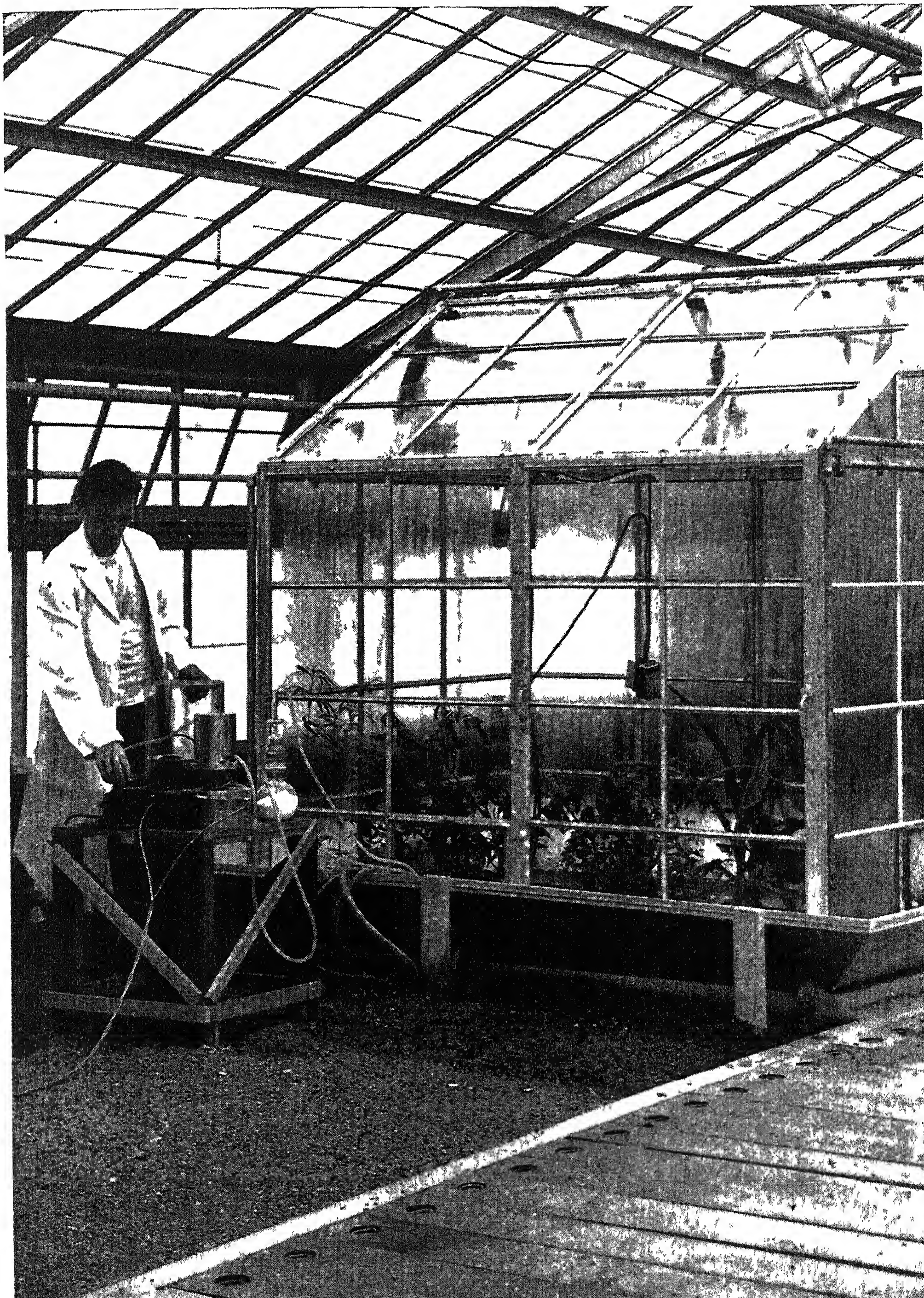
Watching the splendid energy of growth, we feel that every wish of man is satisfied. Spring pleases every faculty, satisfying our sense of beauty and of wonder, at the same time that it provides all that is necessary to feed us and to clothe us, and to supply our luxuries and increasing needs. The fluid that pours out of an india-rubber plant is a fountain of energy comparable with the plant-fountain that was described above, and it makes possible some of the greatest material advances of the age.

One cannot live a day, or notice the common things of life, without coming back to this vital energy of plants and the manufacturing energy of the tender leaves. The coal we burn is only giving back, in the energy of heat, the same energy by help of which sun and leaf and root and stem fashioned out of iron-hard minerals and intangible, invisible gases this hard, unpromising form of carbon on which so much of the material work of man depends.

Plants may supply a fountain of water, or of gum, or of rubber. They may also supply a furnace, not in the indirect way of coal, but by their direct activity. At a certain period in their life a number of plants generate a heat which may seem incredible. We have seen elsewhere that the inside of the bell of a snowdrop flower is often two degrees warmer than the air about it, but accounts are given by writers on the botany of tropical and subtropical places which describe how, in certain plants, notably in *Mauritius*, such chemical energy is exerted that parts of the plant are raised 17 degrees and more above that of the surrounding air; and there is no more telling evidence of energy than emergence of heat.

As we look over the whole field of nature we find signs of forces that baffle and astonish us. A tree can pump up plentiful water to the height of over sixty feet, which is twice as high as any vacuum pump can raise it. We find starch and sugar and a host of valuable substances formed out of hard and invisible and unusable materials. We find the production of electricity — that strange and strong expression of the most mysterious of forces. We find everywhere the exercise of a power of growth by which apparently tender things are able to thrust aside clods, and remove stones, and even shatter solid rocks. Nor must we omit the energy of those bacteria — representing a humble form of plant life — which in and under the soil drive a factory as powerful as that of the leaves, with the same end in view — the alteration of crude and (in the crude state) useless substances for the service first of the plant and afterward of all creation.

IN A RADIOACTIVE GARDEN



Argonne National Laboratory

Plants normally combine carbon dioxide, drawn from the air, and water to form many important food substances. Radioactive carbon dioxide is supplied to the plants in this chamber. All the carbon-containing substances that they produce are radioactive and can easily be traced in the plants' tissues.

THE DEER FAMILY

The One Semi-Wild Creature that Extends its Range at the Expense of Man

THE MYSTERY OF THE ANTLERED HERD

THE man who has never seen live deer, that is to say, the great majority of mankind, always pictures the stag with towering antlers; he does not realize — how should he? — that these massive weapons are developed every year, then cast as naturally and easily as a bird discards its plumage. This growth and discarding of antlers is quite one of the strangest phenomena of nature. It cannot be compared to the method of molting pursued by the larvæ of insects, for that process leads up to a definite metamorphosis beyond which there is no change. This is an annual process. Perhaps it may be more justly compared with the molt of the crab or the lobster, which crawls out of one shell, and at once develops another; or with the successful effort of lowly organisms to replace lost limbs or important organs.

It is this casting of the antlers which differentiates the deer from all other animals, with one notable exception. This is the pronghorn antelope, which is a connecting link between the two families. The prongbuck develops a pair of small, permanent pointed horns from the top of the skull, but from these sheaths of branching horn arise, to be cast every autumn as in the case of the antlers of the deer. This, and other peculiarities, constitute a puzzle, so that naturalists do not quite know where to place the animal, whether in a family by itself or as a sub-family of the *Bovidæ*. As we shall not meet this anomalous animal again, it may be noted that its home is in our western plains region, where it has become extremely rare in recent years.

Antlers are, as a rule, carried only by the male deer. There are exceptions, however. Some females, which are neither unsexed nor infertile, produce antlers when young, and grow them from year to year. And some aged female deer, after rearing several fawns, grow small antlers, as some aged female birds develop plumage approximating to that of the male bird. So, too, female reindeer and female caribou, the American reindeer, regularly bear antlers scarcely distinguishable from those of the males. We cannot say, again, that all stags cast their antlers once a year, for some deer have no antlers; while there is one species of deer, the milu, or Père David's deer, the young stag of which casts its antlers twice a year!

A romantic interest attaches to the animals of this species. The milu has never been definitely traced to its native home; it was known only in the Imperial Hunting Park at Peking. During the Boxer rebellion, the walls of the hunting park were broken down, and the deer fled, and were captured and eaten by the natives. And it is believed that the only living representatives of this interesting species are those to be found on the Duke of Bedford's estate at Woburn, England. Happily they breed there, so there is the possibility of their owner having it in his power to furnish Asia with the nucleus of what may in time become a powerful herd of these animals.

The antlers originate in a pair of bony protuberances on the upper part of the forehead. Upon these develop velvety knobs, which are liberally supplied with blood-vessels and increase in size.

As the animal grows the blood courses feverishly through the investing velvety skin, and bony matter is rapidly deposited, so that in the course of some ten weeks the mighty antlers, which may weigh over seventy pounds — which in the extinct Irish elk are known to have weighed as much as 100 pounds — are completely formed. At this stage the bony rings at the base, through which the arteries pass, begin to thicken and close up, so compressing the blood-vessels and terminating the connection between the antlers and the rest of the body.

THE RED DEER — THE MONARCH OF THE GLEN

The "velvet" in which the antlers are invested is rubbed off against trees or other convenient obstacle, and the stag is ready for battle — a living animal armed with a huge mass of dead bone. Such the antlers in their perfect state really are. They serve for the duration of the breeding season; then the living bone at the base of the antlers is absorbed, and the antler is shed. The bony pedicles almost immediately reappear, the velvety knobs sprout afresh, and the entire growth is renewed. The whole process is unique and marvelous. Here is an animal growing and discarding a great quantity of solid bone every year, yet the mighty rhinoceros perishes when his teeth wear out, for the reason that he cannot continue their growth. If only the elephant could shed and renew its tusks in the same way, it would be in no danger of extermination: we should "farm" elephants for their ivory as we "farm" ostriches for their feathers.

The deer family is an ancient one of eleven genera and some threescore species. Members of the family are to be found all over the world, save in Australia and that part of Africa south of the Sahara known as the Ethiopian region. Their absence from the latter territory can only be explained by the fact that their place is there taken by the antelopes.

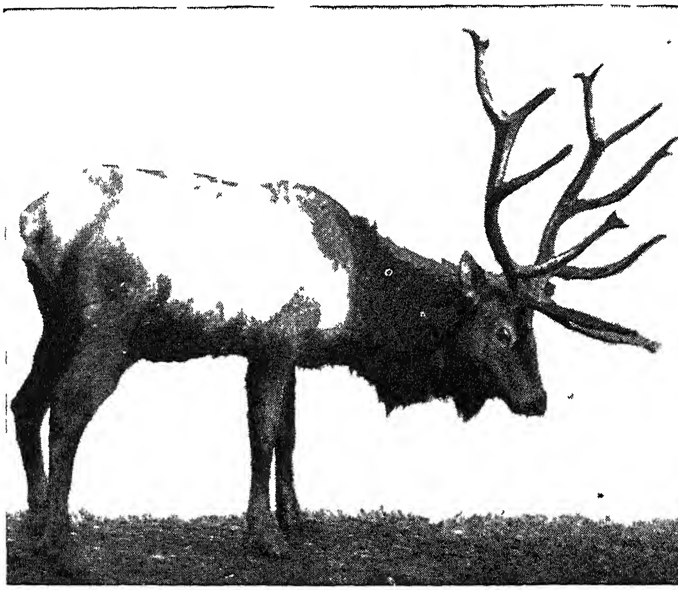
The splendid red deer still has a far extended range, in spite of the denudation of former forest land. Several species are to be found distributed over Europe, northern Africa, North America and Asia north of the Himalayas. Reddish brown of coat in summer, with the head and legs tending to gray, and with a yellowish patch on the buttocks, the red deer in winter assumes a coat of longer hair, which becomes a brownish gray. Standing fully four feet in height at the shoulder, the adult stag may weigh between 300 and 400 pounds, but records of still heavier beasts are kept. These fine animals are still to be found wild in the Highlands of Scotland, but the bulk of them may be described as semi-domesticated. At any rate, in many places they gather during the winter like sheep to be fed by the game-keepers of the estate. Like most of the deer family, they are harmless, except during the short breeding time. At that season, when the stags begin to roar, they are formidable and fierce enough to try the nerves of the boldest man. For all their acquaintance with the sight of human beings, these animals still retain their instinctive terror of man's scent. With the wind blowing towards him, the present writer has walked to within a hundred yards of where a dozen fine stags crowned a solitary Highland hilltop. The deer stared with a sheep-like curiosity and stood their ground, though uneasy.

THE SPLENDID RED STAG OF ENGLAND

ONE OF THE FINEST EXAMPLES OF THE DEER FAMILY, THE EUROPEAN STAG, PURSUED BY HOUNDS

Given a turn of the wind to carry the scent of a man, they would bound away in the wildest panic — except, of course, in the breeding season, when, in such case, a man's life would not be worth five minutes' purchase.

Asia is the home of several allies of the red deer, and one of these, the hangul, or Kashmir stag, stands nearly half a foot higher at the shoulder. These animals are being exterminated by the ruthless manner in which they are slaughtered when, gathering in herds, they descend into the valleys, driven thither by the snowfall on the mountains The nearest ally of the hangul is the wapiti, linked by the former with the red deer.



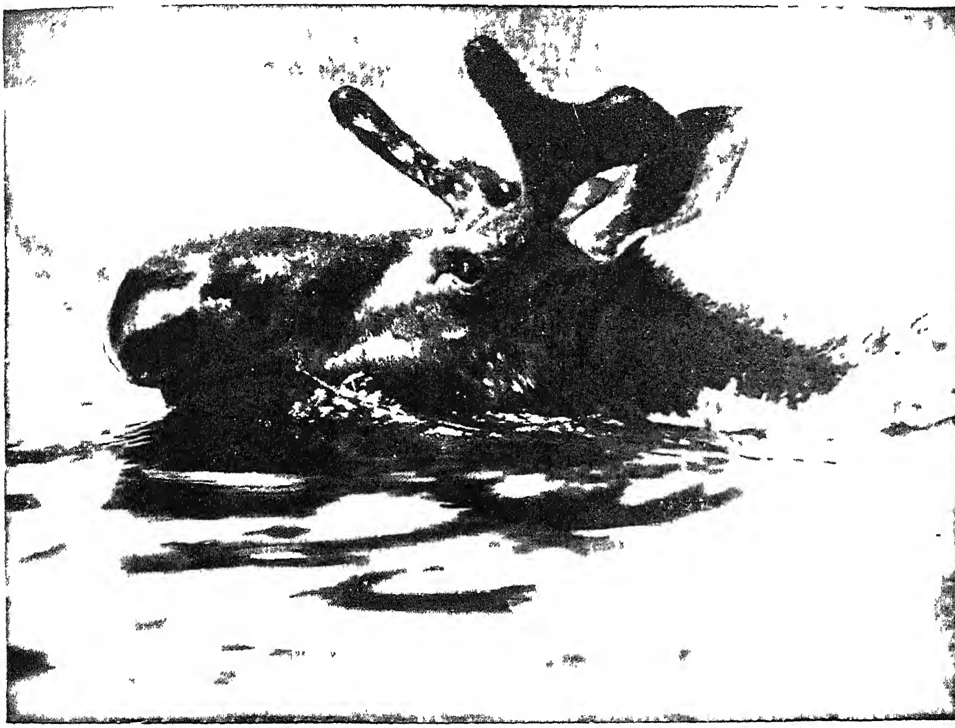
THE WAPITI, COMMONLY CALLED "ELK" IN AMERICA

The wapiti, usually miscalled "elk" and famous throughout the northern half of the American continent, though now in sadly dwindling numbers, is the second largest of the deer tribe, standing, in the biggest examples, four and a half feet in height at the shoulder, weighing from 700 up to 1000 pounds, and carrying prodigious antlers. It might be thought that this bony burden would impede the flight of the animal through the forest, but the wapiti so disposes his head in running that the horns are laid flat along the back, and the antlers may even serve as a protection against overhanging branches rather than as a hindrance.

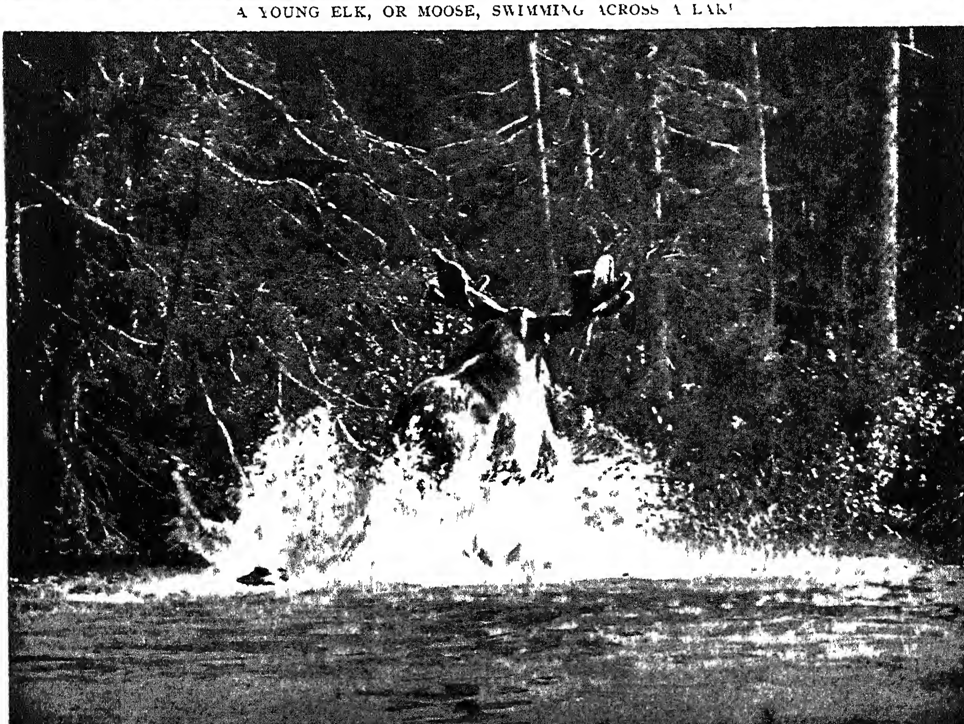
The "elk" is easily distinguished from all other American deer by its well-marked light rump patch. The young, numbering one to three at a birth, resemble other fawns in being spotted with white.

Except during the mating season, adult stags keep apart from the females When the autumn comes, however, the battles between the males are indescribably savage, and at such a period a male wapiti is said by good judges to be, viewed from the point of a possible antagonist of man, a veritable fiend The wapiti, like most deer, is a bold swimmer at need, and capable of considerable speed when running This splendid deer once ranged eastward in the United States to the Appalachian Mountains, and far northwest in Canada. It was everywhere abundant, especially in the West, where it found both shelter and pasturage among the mountain valleys and plateaus from the plains to California. In winter herds numbering tens of thousands would gather and move southward from the snowy north and down from the high hills to spend the cold season in the shelter of wooded valleys.

The animal was very important to the native redmen, furnishing them not only food but valuable hides, etc. There are probably about 40,000 "elk" still left in the United States, chiefly under the protection of law in government preserves. There are 30,000 in the Yellowstone National Park. So vast a herd is this in the Yellowstone that when they assemble for the winter, as is their custom, in the Jackson Hole country, they consume all available food in the region and the government finds it necessary to ship tons of hay to Wyoming to keep them from starving.



A YOUNG ELK, OR MOOSE, SWIMMING ACROSS A LAKE



AN ELK, OR MOOSE, LEAVING A STREAM FOR THE FOREST

The Japanese sika and the European fallow deer are familiar park ornaments. The chital and sambar group—the former a gay and handsome deer of India and Ceylon, and the latter "the woodland deer of southeastern Asia generally"—suggest that, in course of time, we might get a deer which, if permitted to live its natural life, would develop permanent antlers, and not shed them. Red deer hinds at times produce antlers, as we have seen, and the female reindeer which first carried these weapons must have been a "sport" that found antlers useful for the protection of her fawn, and passed on the peculiarity to the race.

In addition to formidable antlers, the muntjac stag is armed with projecting canine teeth in the form of tusks, and, when attacked, uses these with considerable force, so as to produce an ugly gash in the flesh of an antagonist. One species of muntjac, the hairy-fronted, whose short antlers are almost concealed by the bushy hair upon the forehead and top of the head, leads us on to the true tufted deer, natives of China, in which this development of hair is still more curiously pronounced and the antlers increasingly attenuated, while the tusks are developed in proportion corresponding with the diminution of growth of the animal's horns.

JAPANESE DEER WHICH WITH FALLOW DEER ARE KEPT IN PARKS

On the other hand it is not impossible that from the chital or its ally, the sambar, there might arise the curiosity indicated. For there is great irregularity in the shedding of the chital's antlers, while the sambar buck is known at times to carry his for at least two seasons.

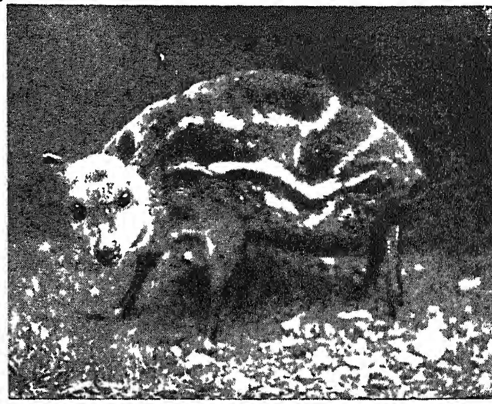
Allied to these interesting animals are the hog deer, so called from their pig-like habit of rushing, when alarmed, with head down through the long grass in which they make their home. This style of carriage applies also to the muntjac, an animal ranging throughout the hill forests of India, Ceylon, Burma, Siam, China, and Malaysia.

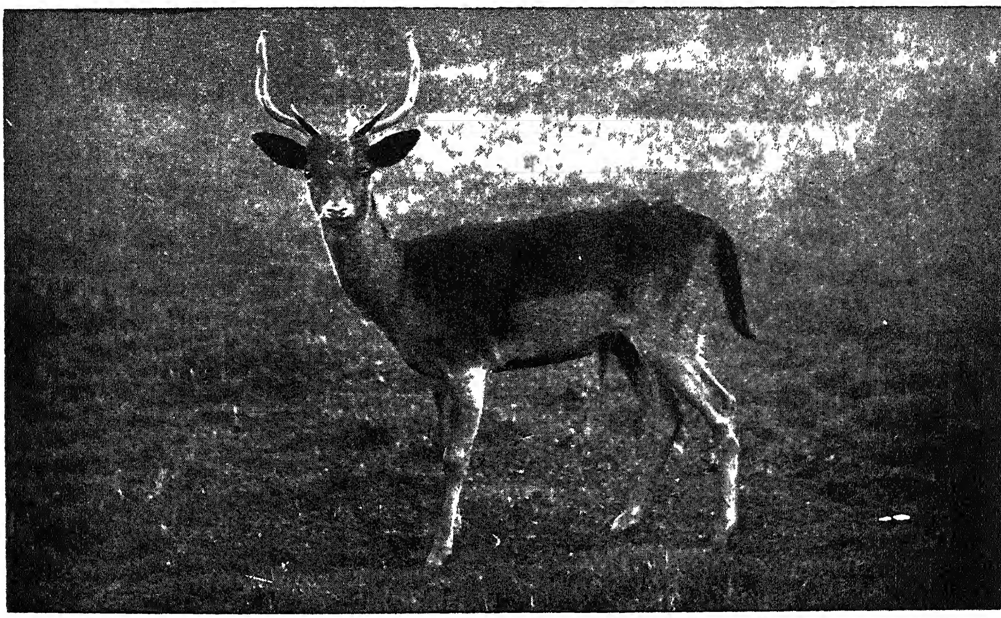
This peculiarity as to dentition reaches its culmination in the musk deer, which, like the Chinese water deer, is destitute of horns, but has the upper canine teeth continued into tusks three inches long.

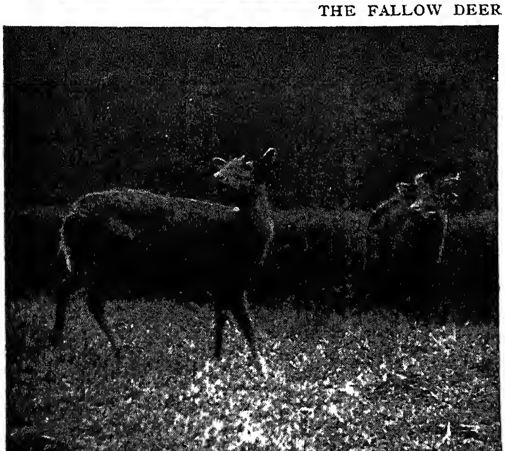
To what extent these implements serve for strife is not certain, but native testimony is to the effect that the musk deer uses the implements in digging up certain bulbs. To catalogue the nature and purposes of the many external glands which distinguish the various species of deer would task the most expert student of the subject, but one, the glandular abdominal pouch, from which this deer gets its name, must not be passed without notice.

NIMBLE DEER AND QUAINT CHEVROTAINS


JAVAN CHEVROTAIN

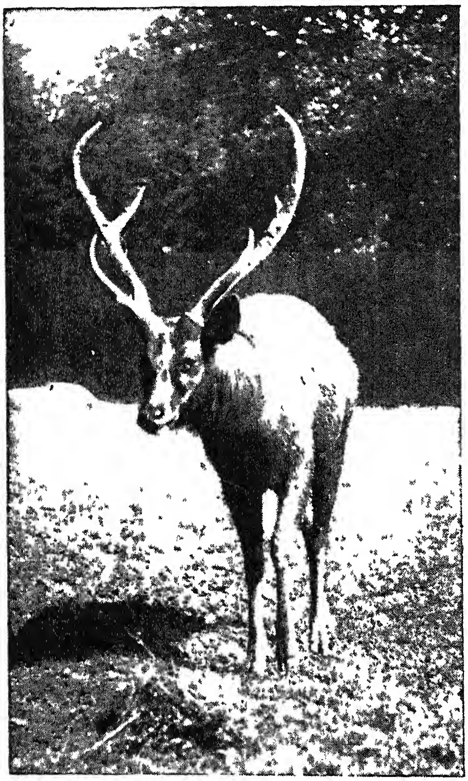

INDIAN CHEVROTAIN


THE FALLOW DEER OF GREAT BRITAIN


INDIAN MUNTJACS


THE MUSK DEER

The gland in the adult male contains a secretion of a powerful musky odor. When first obtained, it is overwhelmingly strong to the human nose, but it rapidly dries, and lo, it is the musk of commerce which scents charms and amulets beyond number. The scent is extraordinarily persistent, the smallest fragment retaining its powerful odor unimpaired for an almost unbelievable number of years.



A FINE SAMBAR DEER

The musk deer are among the smallest of the family, and we pass now to the monarch of them all, the moose, which, though confined to northern North America and Europe once roamed in large numbers as far south as New Jersey and England. Some of the finest specimens are to be found in Alaska and British Columbia—where moose bearing antlers with a span of seven feet have been shot. "A very steep animal" was a schoolgirl's description of the moose, and she certainly had a right conception as to the creature's dimensions, for "steep" it is, between six and seven feet high at the withers

Position taken when resting an interesting development of instinct in the elk

For the purpose of further comparison, it is interesting to remember that a moose standing $6\frac{1}{2}$ feet at the shoulder is as tall as would be a horse of 19 hands! But the moose does not show himself quite to the best advantage, for he carries his short neck in a horizontal position, and lower, therefore, than the exalted withers; and this fact, coupled with the strange shape of the head, gives the animal a somewhat grotesque appearance. The female, lacking antlers, looks still more uncouth, the large, donkey-like ears being quite unlike the trim and picturesque pattern which we expect of a member of the deer family.

But those long ears are not without purpose. When the moose disposes himself to rest or chew the cud, the ears are constantly in motion, one backward, the other forward, and their sense of hearing is extremely acute. Added to hearing is a very keen scent, to which full play is given by an ingenious trick. When he is coming to rest, the elk takes a short turn and sleeps below the wind of his fresh track, so that if an enemy follow the trail he must be heard or smelled before getting within shooting range. This seems a parallel development of instinct to that of the wounded African buffalo, which turns aside to lie down and await its assailant in the same way.

Canada is rightly jealous of the safety of her splendid big game. The shooting of moose is limited by license, and many of the old arts practised for the destruction of this splendid animal are discountenanced. In summer time the moose betakes himself to deep swamps, where he nuzzles far down in the water, immersing his head to the ears, to pull up aquatic plants, making a prodigious blowing to free his mouth and nose of mud and water. This act betrays his otherwise unsuspected presence to the hunter, and it was of old time the practice to row at night with a light in the boat to the spot, and shoot the moose as he gazed in stupid wonder at the flare. This is not done now, nor is it permissible to hunt moose with dogs.

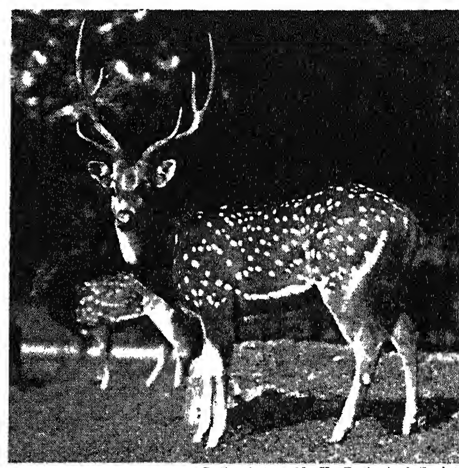
Another popular sport was to hunt moose on snowshoes. It is no longer legal to do so; the animal must be tracked on foot. As it runs with amazing swiftness through log-strewn forests, taking all manner of obstacles in its stride, it requires a stanch hunter to come up with the moose, once it has a fair start. Even should it come to a halt in the forest, it is most difficult to locate, so well do its long limbs harmonize with the saplings around it and its general body outline merge with the background of the forest. Long may this noble animal elude the only foe that it has to fear — the man with a gun in his hands!

The roebuck takes us back to Europe, for this handsome little animal is a native of that continent. Its height when fully adult is only about twenty-five inches at the shoulder, but its proud bearing causes it to seem taller than that. At certain times, the roebuck is a fierce little animal, striking viciously with its forefeet; but, of course, it is not so dangerous as some of the larger deer. For example, a red deer can rip a hound open with its sharp hoofs; while the elk, if approached too closely, will sometimes swiftly turn and trample a pursuer to death. Perhaps, size for size, no animal defends itself so effectively against attack as does the roe deer. Even the doe of the species uses her hoofs with startling effect and butts vigorously with her head.

The taruga (*Hippocamelus antisensis*) is a graceful deer that is found only in South America.

There still remain the smaller American deer, which include some notable varieties, differing considerably in certain respects from those of the Old World. Among these American deer are the South American animals called brockets; they derive their name from the fact that they resemble young red-deer stags, which are also known as brockets. They are distinguished by their tufted heads. The pudus, found in Chile, stand only about fifteen inches at the shoulder; they have small, spike-like antlers. The marsh deer, which have big and complex antlers, are the largest deer of South America; in fact, they rival the red deer in size.

North America has several well-marked species of deer in addition to the moose, the elk and the red deer that we have already described in the previous pages. Undoubtedly the most widely distributed and best known is the white-tailed, or Virginia, deer, which exists in fair numbers all over the United States, southern Canada and northern Mexico. It is one of the larger deer; the male stands some three feet at the shoulders and it may weigh as much as three hundred pounds. The animal is reddish brown in the summer and grayish brown in the winter. The antlers of the buck generally have five points.



Both photos, N. Y. Zoological Society

The axis deer (*Cervus axis*) is found in India and the East Indies. Its coat is spotted with white.

It is primarily a deer of the woodlands and is fond of the water, wading deeply into rivers and lakes to feed on aquatic plants. Its characteristic mark is a triangular tail, the long hair on the underside of which is white. In alarm or excitement, this tail is turned straight up, and hoists a "flag" that is unmistakable in its indication.

The prairies and plains of the interior of North America formerly abounded in bands of a larger deer that avoids the woods and waters that attract the white-tail. In general color it is a fawn gray, but its tail is round rather than trowel-shaped, and terminates in a black tip, which in excitement is waved conspicuously across the white stern of the animal.

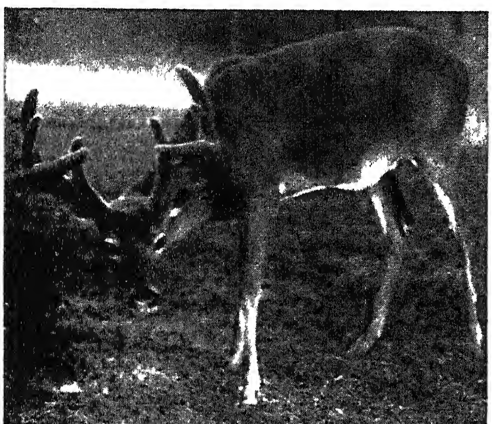


Photo by A A Allen
VIRGINIA OR WHITE-TAILED DEER WITH ITS HORNS "IN THE VELVET"

Its black-tipped ears are of great length and because of this it is known as the mule deer. It is sometimes called the black-tailed deer but this name should be restricted to the Columbian deer of the Pacific Coast. The mule deer is now rather scarce except in certain parts of the Far West but in the time of its abundance its habits were much the same as the wapiti's, roaming grassy plains in summer, and in winter forming into bands, though not into immense herds, and seeking the sheltered, thinly wooded valleys in which to pass the snowy months. It is fond at all times of rough country, rocks, gullies and brush, to which it rushes for safety when disturbed.

The third sort of North American deer is the Columbian black-tail, whose home is in the wooded hills and forests of the coast ranges from Central California northward. It is much smaller than the mule deer, and has shorter ears and a blacker tail. It dwells in thickets and forests, and gets most of its food from the trees, eating little grass. It is fond of climbing to the high mountain tops in summer, but in winter comes down into the valleys.

The caribou differ from the typical deer in that the front tines of the antlers, which are borne by males and females alike, are much flattened and directed forward as in the European reindeer. There are two general types of caribou and probably a number of species, though because of the nature of their haunts the extent of their respective ranges has not yet been thoroughly worked out.

The smaller and paler of these two types is the barren grounds caribou which becomes nearly white in winter. During the summer this interesting deer is found way to the north of tree growth, where it gets a large part of its food from what is commonly called reindeer moss, a species of lichen that grows on the rocks. During the fall they migrate southward to the spruce forests where the snows are less deep, these migrations presenting one of the most remarkable spectacles of the far north, though they have seldom been witnessed by white men. The second type of caribou is called the woodland, and is found in all the provinces of Canada except Prince Edward Island; and formerly, at least, was encountered as far south as Maine and Montana. It is larger and somewhat darker in color than the barren grounds species.

New Zealand, which probably had not a single indigenous mammal, the dogs and bats found by the European discoverers having been almost certainly introduced by the Polynesian settlers, now possesses large herds of red deer, from a few animals sent over from England. So well have the animals profited in their new environment that their size and antlers exceed anything seen in the land of their ancestors.

THE DIGESTIVE SYSTEM

Food in its Course through the Alimentary Canal and the Chemical Action on it before its Absorption

ORGANS WITH MANY AND WITH NO USES

FROM the Latin *alere*, to nourish, we derive the noun aliment, meaning food or nourishment, and also the adjective alimentary, applied to the system of organs in our bodies which exist for the intake and adaptation of food. These, again, are not peculiar to man. Every living thing must have some kind of alimentary system, or it would die of starvation. The amœba may not have developed any special organs visible to our eyes for the purpose, but it must have its machinery of digestion and absorption nevertheless, just as our own white blood-cells have. Function always precedes structure in the world of life, and we can understand neither man nor any other living thing if we invert the true order of evolution.

But the higher the type of organism, the more does it achieve for itself in the way of an alimentary system; and though that of man is in some ways less complicated than what we find in, say, ruminating animals, yet its real complexity is incalculable, and far transcends anything that its mere anatomy can show, as the new study of diet is just beginning to teach us. That, however, is a personal matter, for personal control, and is therefore rightly dealt with under Health in this work. Here we must try to grasp the essentials of the alimentary machine as we find it in man and, above all, to define its place in the "philosophy of the organism".

Most certainly the alimentary system exists not for itself, but for the service of the rest of the body and, ultimately, of the only organ characteristic of man, which is his brain. We eat to live; and to live to eat is essentially and surely to die. The true relation of the alimentary system to the rest of the body is daily expressed in the story of the stomach (typifying the whole system), and the revolt of the rest of the body against it, as told in the first act of Shakespeare's "Coriolanus"; and nothing demonstrates this fact so well as the essential structure of the system. True, it is significant enough that the stomach, for instance, is not itself fed by one molecule of the food it receives, but is fed from the blood in its walls just as the heart is; but even that notable fact, which is true of the entire canal, is less significant than the fact that this canal is what it is.

For it is, essentially, none other than a long tube running right through the body in such a fashion that the body is really outside it, just as the body is inside the skin. To apply a food, such as cod-liver oil, to the skin, or to apply the same food to the inside of the alimentary canal, is essentially the same thing. The process of nourishment begins with absorption — inwards through the skin in the one method of administration, outwards through the wall of the bowel in the other. The body receives no good at all until this occurs, and may starve in the midst of plenty — or with plenty in its midst — until absorption draws the food into the blood, which can then distribute it to the living tissues themselves. And, we repeat, the sheet of tissue, itself alive, through which absorption occurs is not in the least fed by the food which passes through it, but only by that which the blood brings to it upon its under surface.

Alimentary canal the receiving and distributing station for the body's food

All the food we receive we receive through the wall called the bowel or the wall called the skin — in an emergency — yet there is no food for either but what the blood brings back to them. There is no such thing as a skin-food; and even stomach and bowel receive nothing at all for themselves until they have first received, prepared and distributed to and for the rest of the body. Many a patch of stomach wall has died and given rise to a gastric ulcer, though continually flooded with food, just because the little artery supplying it from underneath has become blocked; so that it actually dies in contact with plenty. The facts, we observe, are more complete and significant even than if the stomach and bowel kept for themselves just what they needed, and handed on the rest to the body in general. On the contrary, what remains to the alimentary system is simply what is of no use either to it or to the body — what, in fact, it prevents from entering the *real* body at all. The alimentary canal, therefore, is a long tube, around and outside which the body is arranged, and this tube receives and distributes to the body what of good comes to it, leaving for itself "but the bran" as Shakespeare calls it.

The simplicity of the food-tube through which our bodies are fed

The alimentary system consists of this tube and its appendages. We have already seen enough of the body to guess that the appendages of any system may be very complicated, and may extend very far. We must beware here, then, of supposing that this system is isolated, notwithstanding the definiteness and the essential humbleness of its function. On the contrary, we have now come to realize that its behavior is influenced by the chemical activity of glands that appear to have no connection with it, and we also know that, like the circulatory and respiratory systems, the alimentary is very largely under the control of the nervous system.

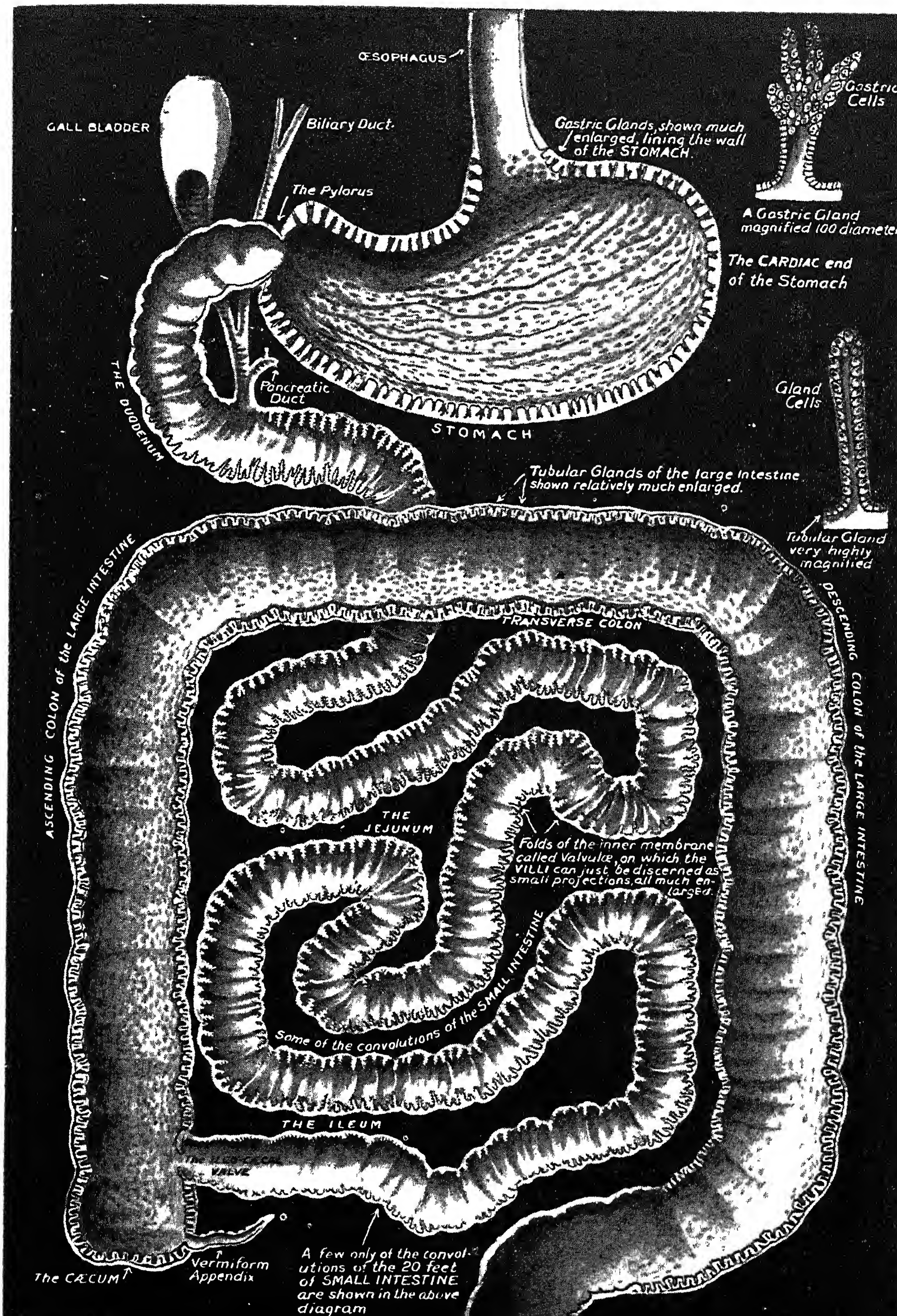
But its principal appendages are unmistakable, and in essentials they are simply to be looked upon as outgrowths, or pouches, developed from the primitive tube. In another section of this work it was shown how the higher animals develop from a three-layered embryo; and now we learn that the innermost layer, called the hypoblast, of this three-layered hollow ball naturally becomes the lining of its primitive gut, or bowel, or alimentary canal. And then, for special purposes, one blind sac or another is found pushed out, as it were, from the wall of the canal at various points, until we find that it has quite a number of such appendages, now taking the form of glands, that produce some special substance of their own in their recesses and send it as their special contribution to the astonishing mixture of chemicals which is called the intestinal juice.

The elaborate mixture of chemicals with which our food is treated internally

The whole tube is lined with glands of various kinds from end to end, each designed in one way or another to serve the alimentary function. But there are some very conspicuous outgrowths, of which the two largest are the liver and the pancreas, each of which produces a special product that is poured into the bowel and has a notable influence upon its contents. Nevertheless, while we recognize the liver and the pancreas in this relation, we must no longer make the mistake of the older physiology, which used to look for the function of an organ and, having found one, was content.

That view was based upon the idea that structures or organs come first, and functions second. But now we realize, with all the wise men, physiologists and poets alike, who ever existed, that function comes first and makes structure. The single cell of the amœba discharges a dozen functions — it is the lung and heart and kidney and liver and brain of the amœba. Therefore we need not be astonished to find that cells in our bodies, or the collections of cells we call organs, discharge more functions than one.

THE DIGESTIVE SYSTEM OF THE BODY



In truth, physiologists are learning that they never can tell when or whether they have exhausted the functions of an organ. Anyone asked "the function of the liver" will reply "the production of bile," and be right so far. The liver does make bile and pour it into the bowel. Similarly, the pancreas makes the pancreatic juice, and pours it into the bowel. But the liver must have at least half a dozen other functions as well as this, and totally distinct from it, and the pancreas has at least one, and probably two, that have nothing to do with making the pancreatic juice.

The same is true even of the walls of the alimentary canal itself. We find that they produce, at one point or another, a digestive juice. But further inquiry reveals novel functions for this juice, perhaps unconnected with digestion; and as we proceed we find such entirely irrelevant functions, apparently, as the production, by glands in the wall of the bowel, of vast multitudes of white blood-cells.

The extraordinary variety of functions in which the human mouth is employed

We proceed, then, to our study of the alimentary canal and the system of which it is the center and oldest part, but we must beware of supposing that it necessarily confines its functions solely to digestion and absorption, and we may even note that the much-berated appendix is declared by some anatomists to be a comparatively new structure in man, not an "ancestral relic," and to have some unknown, yet possibly very useful, function.

When the jaws are clenched in disease, or otherwise, we may have resort to nasal feeding, just as we may have resort to mouth breathing when the nose is blocked. But it is perfectly clear that the mouth is the entrance to the alimentary canal, as the nose is the entrance to the lungs. The case is somewhat complicated in man because of the extraordinary development in him of the power of speech. This has meant that the mouth, tongue and teeth, and also the muscles of the throat, or pharynx, all historically and originally solely concerned with alimentation, have become largely employed for an utterly different function. All these structures were evolved for eating and drinking, for mastication, taste, adding digestive substances to the food, moistening and swallowing it. Yet, one and all, though they are essentially part of the alimentary system, and are thus found in many varieties of full perfection in dumb animals, they have now become, in man, organs of speech as well — and thus *expiration* through the mouth is normal in man. But inspiration is not, and the maxim may be repeated that, unless a man has something to say or to swallow, his mouth should be shut.

The main facts of the mouth, as regards structure and function, are familiar, and need not detain us long. Their special interest for us lies in those features which are specially characteristic of our own species. The first of these are the teeth.

Is the modern degeneration of teeth a stage in evolutionary progress?

Comparative anatomists have always paid special attention to the dentition of animals, not least because teeth and jaws are resistant things, and we have much fossil evidence of this character. Briefly, we note that man has twenty milk-teeth, and thirty-two styled "permanent," and that in number, and also closely in form, these are similar to the teeth of the anthropoid apes, and of no other creature. Some maintain that the dentition of man is unquestionably decadent or degenerate. This statement does not merely depend upon the known condition of the teeth of urban school children, nor even upon the contrast between savage and civilized man, now existing. It depends upon the contrast between the earliest known jaws and teeth of man, thousands of years old, and the teeth of existing men.

The future of the teeth is an interesting matter for speculation, and we may remember, when we consider it, first, that the front teeth, incisors and canines, are of obvious value in adding to the beauty of a smile; and, second, that the incisor teeth are valuable in the pronunciation of those consonants which are called dentals, such as *D* and *T*.

The high importance of the mouth in the preparation of food for digestion

The teeth and tongue and lips and cheeks mechanically prepare the food for swallowing. There are no cheek-pouches in man, as in many of the lower animals. The mechanical preparation of the food in such creatures as ourselves is not all. We *can* bolt our food, as a carnivorous animal does for its own good reasons; but the alimentary system of man is so constructed that, quite apart from any mechanical convenience, mastication is of high importance. The fluids of the mouth not merely soften the food but give it a smooth coat for its passage to the stomach. They come from six important outgrowths from the alimentary tube: the salivary glands, three on each side, which produce a special secretion. These glands are the *sublingual*, lying under the tongue, the *submaxillary*, lying under the lower jaw, and the *parotid*, lying in front of the ear, which makes itself evident in the mumps. In structure these glands are not unlike the pancreas. Their secretion is under nervous control, and can be excited in many ways — through the eye, or the nose, for instance, as when we say that our mouth "waters".

The instinctive cleverness of the organs around the throat in swallowing

Saliva is markedly alkaline, and is probably an important factor in the protection of the teeth from the attacks of acids, such as are liable to be produced by microbes in the mouth. In poisonous snakes the secretion of certain of the salivary glands is modified, becoming intensely dangerous to other animals, and, instead of being carried by a duct to the mouth, is led through certain teeth, hollowed for the purpose, and is forced out through them by the snake's "strike" in the act of biting.

The actual digestion which occurs in the mouth is, of course, slight, for the time is so brief. Nevertheless, the food is impregnated with a digestive fluid, and the digestion really initiated in the mouth, dependent upon fluids secreted by outgrowths from the mouth, proceeds steadily in the stomach for from twenty-five to forty-five minutes after the food is swallowed by the individual.

But this swallowing deserves some attention. Only when we study its disorders in cases of nervous disease do we realize what an extraordinarily complex act it is. It is partly voluntary and partly reflex, large numbers of muscles being involved, including the many muscles in the tongue, those of the soft palate and the throat, and those which guard the entrance to the larynx. The food must not pass upwards into the nose, and it must be steered or shot past the larynx. All we do is to pass the food to the back part of the tongue; and the reflex machinery does the rest.

The new-born infant has this indispensable mechanism in perfect order, and it works at once, without a hitch, though it has never had any practice. A special deglutition center in the lowest part of the brain, just at its junction with the spinal cord, links together and coördinates the activity of the groups of nerve-cells from which run the nerves that control all the muscles in the act of swallowing.

The involuntary wave-like action by which food is propelled in the food-tube

Difficulties are at an end once the food or drink has definitely entered the gullet. This is the much narrowed continuation of the alimentary tube, of which the first part is called the mouth, and the second the throat or pharynx. The muscular tissue of the gullet, or œsophagus, is smooth or non-striated, and its action is quite involuntary. It contracts in a rhythmical kind of wave, somewhat after the fashion of a worm, and this action, found in the alimentary canal and elsewhere in the body, is called "peristalsis". It is the obvious means by which a muscular tube will seek to drive anything along its interior. Even the rapid wave of contraction that runs from the base to the apex of the heart is essentially peristaltic; but we must clearly remember that the pulse in the arteries is not peristaltic, and that their muscular tissue is incapable in man of what we understand as peristaltic action.

How science has enabled us to watch the inside of the body

Under the study of the senses we shall learn that the nerves of taste do not extend far into the throat, and not at all into the gullet. After all, taste is not primarily for our pleasure, but for decision and guidance. It would be of no use when the time for decision has gone, which is when the act of swallowing has passed beyond our control It takes some four or five seconds for the food to be impelled through the gullet to the stomach, but fluids drop, and arrive, before the peristaltic wave has more than started.

Observations upon the behavior of the contents of the alimentary canal can, of course, be made nowadays if we include in the food some metallic salt, such as bismuth, which renders it opaque to the Rontgen rays. Lastly, we note that the peristaltic wave in the œsophagus is capable of being reversed, and that this reversal is normal in the ruminant animals which "chew the cud".

At its very end, the gullet passes through a special aperture in the diaphragm, or midriff, and thus leaves the chest to enter the abdomen, where it becomes continuous with the stomach. This is the most capacious part of the entire canal, existing primarily as a temporary receptacle. It has other important functions, but is in no way necessary to life, as modern surgery has often proved.

The essential action of the stomach upon our food is that of a churn

The essential structure of this part of the canal does not differ from what we observe elsewhere. Its outside is constituted by a coat from the peritoneum, after the manner we observed in the case of the heart and its pericardium. Its principal thickness is constituted by the next coat, which is muscular; and it is lined by a "mucous membrane," crammed with a variety of glands, which secrete the gastric juice.

The first function of the stomach is to be large enough to hold a meal, so that we do not need to be constantly eating. Secondly, it must mix and churn the food, which it does by a systematic employment of peristalsis, driving the food backwards and forwards steadily so long as it remains within the stomach at all. This is undoubtedly a most important function, and one is little likely to prosper if the stomach becomes flabby or dilated, so that it can no longer act as an effective churn and sends the food onwards before its condition is suitable for the bowel.

The stomach an organ not for food-absorption, but for food-preparation

For we must definitely state as the third function of the stomach that of guarding the bowel. Just at the point where the stomach narrows down and leads into the bowel, we find what is the strongest and thickest ring of muscular tissue in the whole course of the alimentary canal. This pylorus, as it is called, has the important function of allowing not one drop of the gastric contents to pass onwards into the bowel until they have been reduced to a proper consistence and condition. This is usually a matter of some hours, and meanwhile the gastric contents escape neither onwards nor backwards, nor yet do any of them "leak" in any appreciable quantity through the walls of the stomach. This is not an organ of absorption, but of reception, churning, protection and digestion.

The first stage of gastric digestion, however, is in the stomach, but not of it. The alkaline mixture that left the mouth is churned to and fro by the stomach and further softened — a process which has limits, however, for the stomach has no teeth and cannot masticate — while the special ferment of the saliva, called ptyalin, proceeds to digest the starch in the food, turning it into sugar. This is the only form of digestion that the saliva can achieve, and if there be no starch in the food, as, for instance, in the diet of an infant, which is the starch-less fluid called milk, no digestion can yet occur. On the other hand, if there be starch in the food, as in such common articles of diet as potatoes and bread, it is highly desirable that its digestion should proceed at this stage, for the stomach produces nothing that can digest starch.

How the stomach daily achieves chemical action beyond the power of the chemist

After the interval named, the gastric juice begins to flow. It is very definitely acid, the acidity being due to the presence of free hydrochloric acid — a most extraordinary substance to find in such a quarter.

It is somehow produced from the sodium chloride, or common salt of the diet, by means of the cells of special glands in the stomach wall. It is, we understand, by no means produced from the salt in the food now being digested, but from the salt in the blood which has received it by absorption of previous meals from the bowel. Sodium chloride is a most stable compound, and a chemist who would be asked to decompose it and to produce hydrochloric acid, in his laboratory, at the temperature of the body, would reply that such a feat was wildly impossible. And yet the body does it every day.

The whole series of digestive processes an interdependent sequence

The digestion of starch by ptyalin ceases shortly after the hydrochloric acid is produced, for the gastric contents now become markedly acid, and ptyalin can only act efficiently in an alkaline medium. But we are to note that, in this as in many other cases, there is a natural rhythm in the chemistry of the body. The students of drugs know that the fashion in which to call forth an acid secretion is to apply an alkali, and *vice versa*. Therefore, the alkaline saliva may be the natural excitant of the acid gastric juice, which would then mean that the more honestly we chew, the better will be performed, not merely the first, but also the second stage of gastric digestion. And, further, it may be the acidity of the gastric contents, when poured into the bowel, that stimulates the production of the intestinal secretion and of the pancreatic juice, both of which are markedly alkaline. Thus we see that the whole series of digestive processes is largely an interdependent sequence, and that it is our business rightly to start that sequence by proper mastication.

The characteristic ferment of the stomach is called pepsin. The action of all ferments is specific, not general. This ferment can digest proteins, and proteins alone. It requires the aid of hydrochloric acid, but that acid is not the actual digestive agent. The peptic digestion of the proteins of the food, assuming such to be present, may occupy several hours before the pylorus considers, so to speak, that the gastric contents are fit for reception by the bowel. But this digestion is seldom really complete, and is of small importance compared with the digestive processes in the bowel itself.

It is merely a popular delusion that digestion is essentially an affair of the stomach, a fact which becomes clear enough if we note, first, that the stomach has no action of its own upon starchy foods; second, that it has no action whatever upon fats in the food; and, third, that even its special ferment, pepsin, is weak and inadequate compared with the ferment of proteins which the food is now about to encounter.

A part of our body that we might be much better without

The next part of the alimentary canal is called the bowel, in general, and may be divided into the large and small bowel, or gut, or intestine. Of these, the small intestine comes first, and its coils occupy several yards of the length of the whole canal, but the large gut, which succeeds it, is of larger caliber, though much shorter and vastly less important. The large gut follows upon the small gut at a definite spot in the right-hand lower quadrant of the abdominal cavity, and close to the junction we find the curious little blind sac called the *appendix vermiformis* — or "worm-like appendage" to the bowel. The large bowel ends in a straight portion called the rectum, by which the remains of the intestinal contents are conducted from the body. No more need here be said about the large intestine, except that Professor Metchnikoff and others have adduced powerful arguments in favor of the view that this is a very nearly superfluous, if not dangerous, part of the body.

Very different is the case in many of the lower animals, whose diet is of a different kind. But in us, though the large intestine is far shorter than in many animals, it is probably more than long enough. No digestion occurs in it. The quantity of waste matter in our diet is relatively very small — often, apparently, too small even to stimulate the large bowel to peristaltic action. Further, it has become the home of microbes, which are only too apt to flourish there beyond all safe limits, and produce poisons which enter the blood and injure us. All this question, however, so closely concerns health, and is so largely under our own control, that it must be discussed elsewhere. It issues in the commonest malady of civilized life, which is constipation.

The stomach as the slaughter-house of the enemies of the body

Meanwhile, we have the small bowel to deal with We note, first, that it is the most delicate, the most skilful, and the most versatile part of the whole alimentary canal. As such it requires protection, and we have already seen how the pylorus of the stomach stands at guard over the entrance to the bowel. But the stomach does more. Hydrochloric acid is a powerful antiseptic. Numerous observations on mankind and the lower animals, and not least the new work done by the Tuberculosis Association in this country, and work on the same disease abroad, show that the stomach must have great powers of killing microbes. It does not always succeed; but the healthy stomach, duly producing a sufficiency of hydrochloric acid, must kill innumerable dangerous microbes, and every doctor knows the lamentable consequences when this precious acid is not produced. Normally, the upshot must be that the chyme, the name given to the food as it enters the bowel, must be not merely churned and in part digested, but it must also be very largely sterilized, to the immense advantage both of the bowel and of the body.

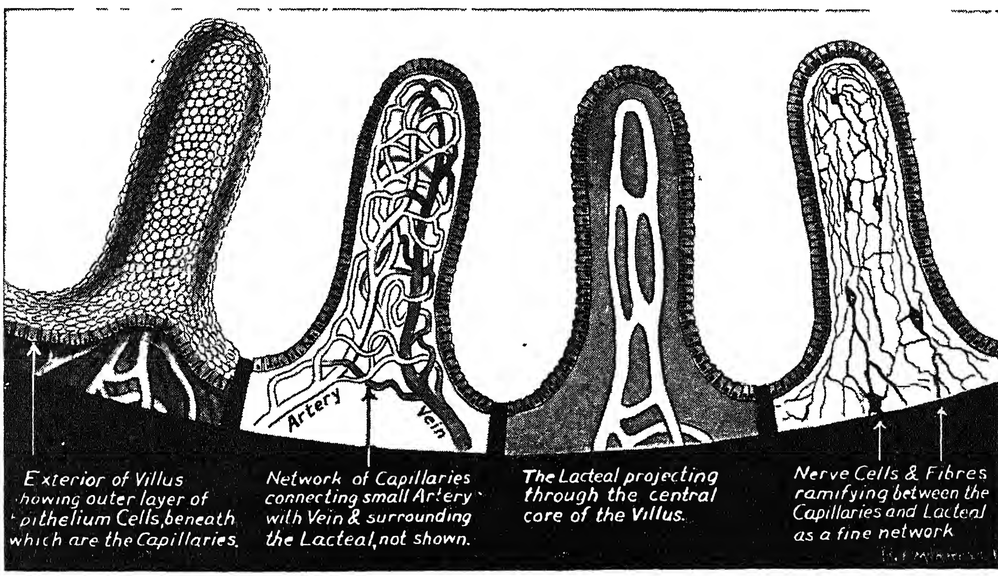
The small bowel produces digestive ferments of its own. As our knowledge of this subject increases, we find that where we thought there was one ferment there are really half a dozen. But probably, even so, the bile from the liver, and especially the pancreatic juice, are more important than the materials produced by the bowel itself. These special secretions must be considered further when we come to look at the glands of the body. Meanwhile, we note that, in the upshot, digestion occurs in the upper part of the bowel. The digestion of starch into sugar by means of the saliva, begun in the mouth and continued in the stomach, is carried out far more efficiently in the bowel by means of one of the ferments in the pancreatic juice. The digestion of proteins by the gastric juice, begun rather than effected in the stomach, is thoroughly completed in the bowel, not by means of pepsin, which cannot act at all in the alkaline fluids of the bowel, but by means of another constituent of the pancreatic juice. A third constituent of this juice digests the fats of the food, which have hitherto undergone no digestion at all.

Popular misconceptions removed as to where digestion is actually carried on

All this is done in the bowel, though only subordinately by it. Its own feat is of a wholly different kind, for which, however, all that has gone before is only a preparation. The small bowel is the *organ of absorption*. We live neither by what we swallow nor yet by what we digest, but solely by what we absorb. This process is not mechanical, but vital — so palpably vital that not even in the dull stupidity of the materialistic creed of the nineteenth century did physiologists suppose that the process of absorption is a mere leakage through the wall of the bowel into the blood. The characteristic of the wall of the small bowel is that it is covered with millions of tiny, glove-finger-like projections called the intestinal villi. Each villus is covered with a single layer of deep, nucleated cells. Within it are two sets of vessels — a loop of capillary blood-vessels, and a corresponding supply of lymph-vessels, called lacteals. The cells of the villus recompose the digested fat in the bowel (for it has been turned into strange

things, such as soap and glycerine), and pass it into the lacteals. These carry it away, and after a meal their contents give them a milky appearance from which they derive their name. They are really just lymphatic vessels bearing this special milk-like burden, called chyle, from the bowel.

The other valuable constituents of the intestinal contents are absorbed by the cells covering the villus, and are thence passed into the blood. The fact is easily stated. What happens is, however, beyond our utmost powers to explain. The cells of the villus take the materials into which the proteins of the food have been broken up by digestion, and build them into new proteins, human and only human, which then become the normal proteins of human blood. These were not in the food, save only in cannibalistic feasts where human blood was consumed; but they were constructed, for the first time, by these cells, and by them we live. Any other proteins but those of human milk, injected directly into the blood, are immediately removed as poisonous, which they really are. That is what we really mean by "intestinal absorption," and with this achievement our brief treatment of the alimentary system properly closes.



HIGHLY MAGNIFIED DIAGRAMS OF THE SMALL PROJECTIONS IN THE ALIMENTARY CANAL, BY MEANS OF WHICH THE NUTRITIOUS ELEMENTS IN THE FOOD ARE ABSORBED BY THE BLOOD

The astonishing accuracy of Shakespeare's statement of scientific facts

It is astonishing to think how much of all this, somehow or other, Shakespeare knew. He makes the stomach say —

True is it, my incorporate friends (quoth he),
That I receive the general food at first,
Which you do live upon: and fit it is;
Because I am the store-house, and the shop
Of the whole body: but if you do remember,
I send it through the rivers of your blood,
Even to the court, the heart — to the seat o' the brain;
And, through the cranks and offices of man,
The strongest nerves, and small inferior veins,
From me receive that natural competency
Whereby they live. . . .
Though all at once cannot
See what I do deliver out to each;
Yet I can make my audit up, that all
From me do back receive the flour of all,
And leave me but the bran.

The fable goes back at least as far as Æsop, but Shakespeare's version, taken from Plutarch's life of Coriolanus, is far better than Plutarch's, and anyone who has dissected and "microscoped" the alimentary system can only gasp at genius which, without acquired knowledge, can pen so accurate a statement of the facts.

THE ELABORATE AND ORNAMENTAL COSTUME OF NATIVE CHIEFS OF CENTRAL AFRICA

DRESS AND ITS PRINCIPLES

The Essential Purposes Served by Clothing and the Qualities Needed for Such Service

DO WE SACRIFICE USE TO DECORATION?

PLAINLY we must begin by asking why, in point of fact, we do clothe ourselves, and why we should clothe ourselves. We shall soon see that there are three distinct purposes in view — decoration, decency and health. But in this work our business is scientific, and in this section hygienic. We cannot, therefore, consider the problems of art, of political economy, or of conventional morality, which are intermingled with the hygiene of clothing. For our purpose we need note only two or three points of general interest before we confine ourselves to the third and last use of clothing.

The other Primates need no clothing — they are already clothed — but man's is a naked skin, throughout life, like that of the newborn or very young of many of the lower animals, which are well clothed with fur or feathers in later life.

Only in the tropics, and only there under the sheltering shadow of trees, does he find a combination of warmth and shade which is just suited to nakedness. To endure the heat of untempered tropical sunshine, or the cold of regions but a step removed either north or south, he requires artificial protection.

Yet the historical evidence seems clear that the earliest assumption of clothing by man was for purposes of decoration. The desire for personal decoration is irresistible; and so we find that decoration precedes dress, or use, in the history of clothes. In our own day, the complication remains; and the hygienist is compelled to fulminate against practices in the matter of clothing which subordinate health to decoration or what is thought to be such. After all it is the clothing which best serves health that, on the whole, also best serves the interest of grace and beauty as well.

The hygienic or protective function of clothes, however, is not quite simple in itself, for there are varying requirements which cannot be realized until we begin to think about them and which ultimately depend upon the strange evolution of the body of man, which has been described in another section of this work. Very generally we require clothes first—in order to keep us warm. There are times and places that furnish exceptions to this rule, but it is almost constant, and obviously corresponds to the unparalleled exposure and defenselessness of the skin of man.

This exposure cuts both ways. It threatens us with cold, and it threatens us also with heat. Not a hot state of the air, however, but only radiant heat, is what our naked skins have to fear. So far as excessive heat of the air is concerned, clothes can only make our case worse. But they may be indispensable for the protection of our skin from the shafts of direct sunlight.

In parts of the world where there is much strong sunlight the white man protects himself with umbrella, pith helmet and white cotton or pongee skeleton suit. We should remember that we are especially exposed, owing to the lack of much pigment in the skin, and that many of us early tend to lose that natural protection of the skull and brain with which nature endows us.

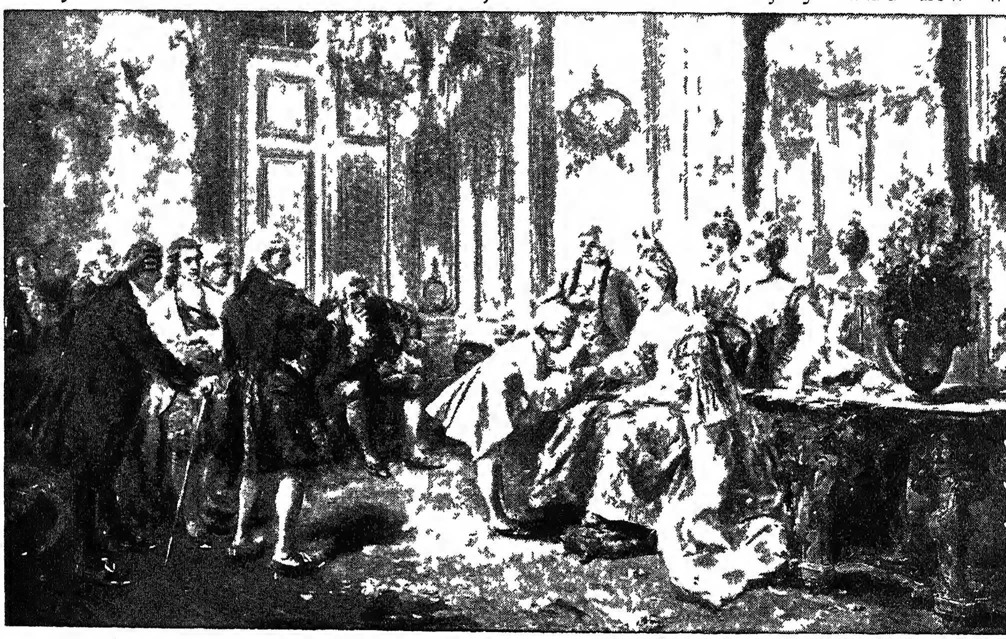
But these two functions by no means exhaust the protective or hygienic function of clothing.

Clothes protect from dirt, or should be used to do so. No doubt it is true that only too often we use clothes much after the fashion in which the domestic filter was wont to be used — not merely to catch dirt, but also to keep it. If we know how to clothe ourselves, and attend to our clothing, our clothes keep us clean, and afford protection alike from dead and from living dirt.

Fourth and last, certain parts of our attire perform valuable functions in protecting parts of the body from mechanical injury. A special instance of this is the sturdy helmet of the construction worker, which undoubtedly supplements the skull in the all-important task of affording mechanical protection to the brain within. The occasional use of a hard and rigid piece of clothing for such purposes, and in such a place, however, has little to be said against it.

Altogether different, as we shall see, is the employment of any such rigid protection for the trunk of the body, and most especially for its upper portion, which must necessarily expand and contract if we are to live. But at the lower end of the body clothing may constantly serve the purpose of mechanical protection for the strangely naked and ill-protected feet of man — man the traveler, the pioneer, the path-maker of the living world. We have seen elsewhere how remarkable are the feet of man from the mechanical point of view. They always and everywhere are advantaged by clothing, but we shall find that the problem of helping them without hurting them is almost insoluble

Such, then, are the four protective or hygienic functions of clothing — to keep us warm, to protect the skin from direct sunlight, to ward off dirt and to protect such ill-protected structures as the feet from mechanical injury. And now we may lay down the first principles which should be obeyed in meeting these indications. Once we grasp them — but not till then — we are fit to face the details of the clothing, inner and outer, of the various parts of the body.



THE OVER-ELABORATION OF COSTUME IN THE POMPADOUR PERIOD IN FRANCE

We said, first, that clothes keep us warm, and the phrase is accurate. We may be warmed from without by sunlight, hot water bottles, open fires, or steam radiators; but the warmth that results from the wearing of clothes is no less important. We should bear in mind that clothes do not produce any heat; they serve to keep us warm by preventing the outflow of heat.

The object of clothes — to keep in the warmth, not to keep out the cold

Heat, of course, is a physical reality, but there is no such thing as cold, which is merely the absence, or rather the relative absence, of heat. We talk colloquially of keeping out the cold, but there is no such thing to keep out. Keeping out cold is keeping in the heat; and thus what we call warm clothes are not at all clothes warmer than their surroundings, for they are indeed of just the same temperature as their surroundings, but rather clothes which are bad conductors of heat, and so keep in our warmth.

Since clothes constantly tend to retard the flow of heat from the body, and since the body must never rise beyond a certain temperature, plainly there is a relation between the amount of clothing one wears and the amount of combustion that occurs in the body. One should expect the people who produce least heat to wear, on the average, the most clothing, and that is quite obviously the case. On the whole, the lithe, active, mobile, energetic people wear less clothing than people of the opposite habit, because they are producing more heat and must not too much retard its outflow.

The close and important relation between diet and dress, food and clothing

This interesting point raises another — the connection between diet and dress, between food and clothing. The future must work it out, and decide the best course for health. But, plainly, the more we obstruct the outflow of heat from the body by clothing, the less food of the fuel type do we require. Probably much of the controversy between people, scientific and unscientific, as to diet would be resolved if they made their observations under conditions of constant clothing and external temperature.

There are arguments in favor of light and in favor of heavy clothing. Good, warm clothing, as we call it, must tend towards economy in the matter of the fuel-foods; and economy in diet is a matter of national, and often of personal, importance. On the other hand, a rapid production and disposal of energy in the body may tend towards a more active and enjoyable life; and it may also involve greater protection against microbes.

The controversial claims of light clothing and of heavy clothing

If we adopt the plan of light clothing, which involves the consumption, certainly not of the ordinary grossly excessive diet, but of a larger diet than would otherwise be required, plainly we must assume that the organs of excretion — or, to be precise, the kidneys — are healthy. For the more one eats, the greater is the work inevitably thrown upon the kidneys; the more furious the furnace, the more abundant the ash. Hence a simple and cardinal rule for all cases where the kidneys are either diseased or somewhat unequal to their work, or liable, with advancing years, to become so, must be to lighten the work of the ill or threatened organs; and one way of doing so is to clothe warmly.

This has a double action, and we must recognize both parts of it. First, as we have suggested, it facilitates a reduction of the diet by better maintaining the temperature of the body. Second, the warm clothing encourages the action of the skin, which is itself an organ of excretion, and which can thus, to a small but valuable extent, bear some of the burden of the kidneys.

The body not made for clothes, but rather clothes for the body

Let us pass now to another of the first principles of clothing — one of universal application, though constantly outraged in practice. It is that clothing should be loose. The body was not made for clothes, but clothes for the body. Nature has not meant or expected the movements of the body as a whole or of any of its parts upon each other to be restricted by anything more than the atmospheric pressure, which bears equally on every part, and thus incommodes none. Thus, directly we assume clothing we run the risk of pressure or restriction of movement.

A tight hat or a tight collar must affect the movement of blood in the veins, especially of the scalp and the neck. Veins, as a rule, are nearer the surface than arteries, they have much thinner walls, and the pressure of the blood within them is much lower. For these three reasons it follows that veins are specially subject to be affected by external pressure. In such a case as either of those quoted, the effect must tend towards congestion of the scalp with venous — that is, useless blood.

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A CHINESE WOMAN OF HIGH RANK, SHOWING THE NOW OBSOLETE CUSTOM OF BOUND-UP FEET

Similarly, the pressure of ill-fitting shoes more or less deforms the toes of every one who wears them.

If the pressure of clothing extends to the walls of the abdomen, harm is done there also. The abdominal wall ought to be able to hold itself upright, to move freely in walking and breathing, and to encourage the movements of the bowel within it. If it does not do so, constipation is encouraged. But it will not do so if it be supported or hampered from without.

Therefore the rule is that, from top to toe, all pressure of clothing is undesirable. It cannot be wholly avoided, owing to the weight of one's clothes, but it must be kept to a minimum, it must be evenly distributed, and should be largely borne by the shoulders, which can bear it best. And, on closer observation, we find that the outside pressure of clothing may simply starve a limb or other part by depriving it of its blood supply. This is the secret, largely, of the now obsolete Chinese method of limiting the growth of women's feet. The young feet are so tightly bandaged that they are starved and dwarfed.

Many people suffer from cold hands or feet because they ignore the rule that clothing should be loose. If a glove or a shoe be very tight, the hand or foot is starved of blood; for the extremities of the body are maintained in temperature by the blood, making practically no heat for themselves. The proper way in which to keep one's hands and feet warm is from within, and this can only be done if we allow the warm blood to enter them freely.

The greater warmth of loose clothing owing to its imprisonment of air

A motionless or slowly moving gas is a bad conductor of heat. We all know the difference between still air and air in motion, as regards cooling effect. It follows that our clothes keep us warm not merely in themselves, but because they partly imprison a good deal of air within them. This, of course, can only be the case if one's clothing is loose. A certain amount of a given material and texture is warmer as a loose garment than as a tight one, simply because it imprisons, as a loose garment, a good deal of air, and we are thus clothed with air as well as with cloth. Other things being equal, the warmest clothing would, indeed, be air-tight clothing; but we all know that it does not do to wear habitually a close-fitting waterproof which is air-tight, and indeed we should see to it that our clothes are ventilated as well as our rooms. Two or three layers of loose clothing will partly imprison a quantity of air between them, and furnish as good a kind of clothing as can be wished.

The lesson of lightness with warmth to be learned from the coats of animals

The next general question is as to the material of clothing. Here we may take a lesson from our animal allies; and we soon learn that hair is the natural and characteristic clothing of a mammal, in such forms, for instance, as the fur of the rabbit or cat or seal, and the wool of the sheep. Everywhere, therefore, where warmth is desired, we adopt such materials. But it is an utter delusion to suppose that material is everything, as such. On the contrary, the important fact about the natural material is its admirable and, unfortunately, inimitable texture. The coat of the sheep is not merely warm, but it is light, highly absorbent and perfectly ventilated.

Very often we take this exquisite material, convert it into a dense, inflexible, non-absorbent texture, and suppose it will necessarily make perfect clothing because it is still made of wool. The sheep's advantage can be realized if we consider the case of a man wearing a sheepskin coat. He is wearing not only the sheep's clothing, but also the sheep's skin, which he puts on outside his own. Nevertheless, it is possible to weave wool into light, warm, air-holding textures which still retain some of the properties of the natural coat. And this must be seen to, for there is another essential of clothing—it must be absorbent.

The skin, as we have seen, is an organ of excretion; and our problem is to interfere, to some degree, with its output of heat, while not interfering at all with its output of dirt.

The need for all our clothing to be in a high degree absorbent

Therefore, at the very least, the changed layer of clothing next the skin must be absorbent, and this is the more necessary the more complete and close the clothing be. The skin needs no absorbent arrangement if it be left alone, as the unclothed face suffices to prove; the problem only arises when we start to clothe it. And the great virtue of wool next the skin, when it is of suitable texture, is that it is highly absorbent.

When it is of unsuitable texture, its virtue goes out of it. This is one of the numerous grounds on which we are bound to condemn the old-fashioned "chest-protector". It is really a chest-weakener, by its interference with the functions of the skin of the chest.

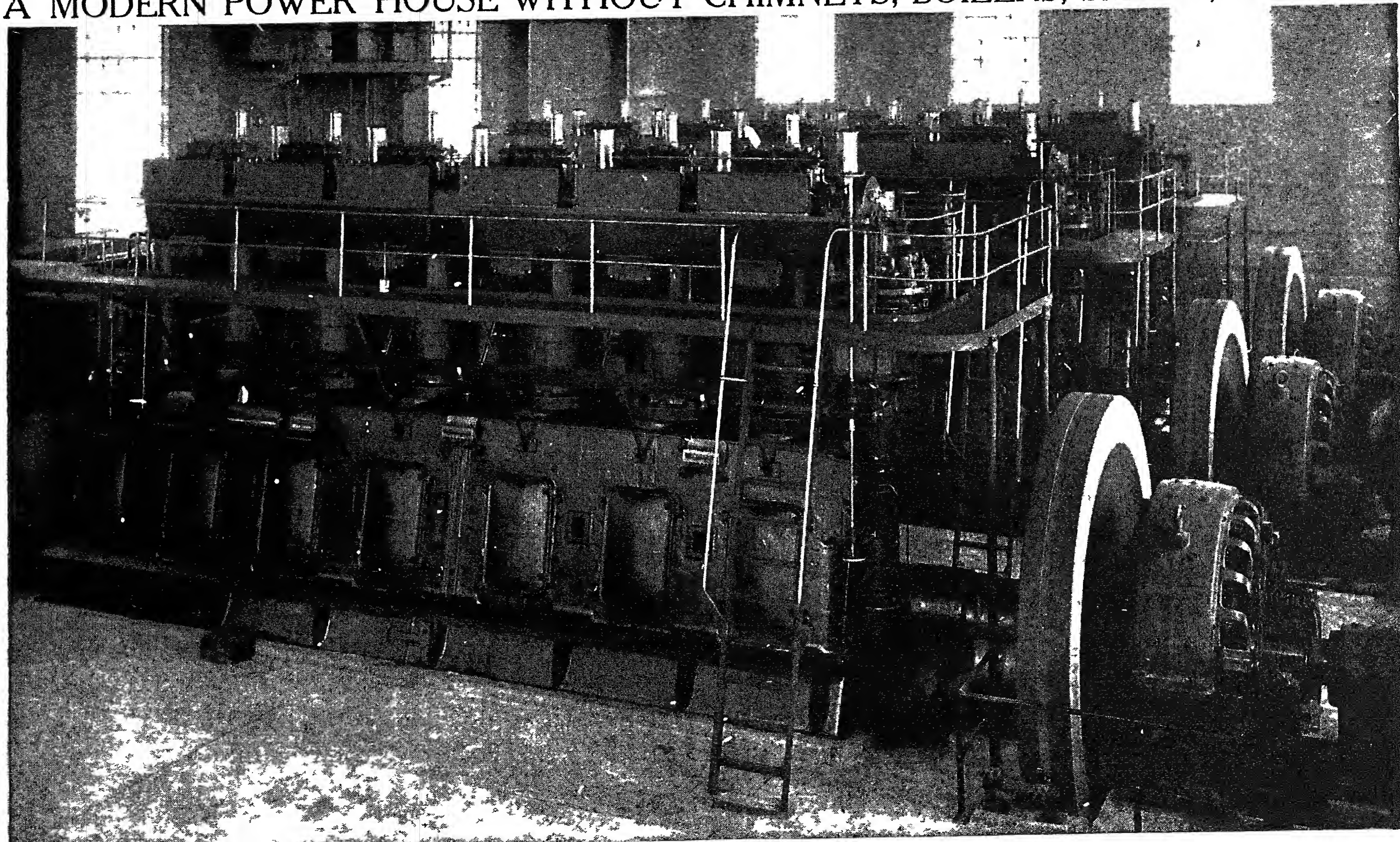
Some people cannot wear wool next the skin, for it causes them too much discomfort, and may even produce what is called a "flannel-rash". Such people must, nevertheless, wear sufficiently absorbent clothing next the skin; and in recent years manufacturers have competed in the production of a large variety of underclothing made of silk, linen, cotton, or combinations of these, which are quite absorbent, and freely to be recommended to those who find them warm enough. For it is certainly not necessary for health to wear wool next one's skin if one be otherwise kept warm enough, and if what one does wear be absorbent.

Principles of clothing based on simple physiological facts of the body

What this question of absorption really means we discover when we are told that the average man disposes of about twenty-five ounces of water by his skin every day, together with various gases and a good deal of oil. This simple physiological fact suggests that one should chiefly rely upon the outer clothing for the business of maintaining warmth, while the underclothing should usually consist of materials that are absorbent, cheap, very easily, frequently and thoroughly washable.

Such, in outline, are the first principles of clothing, considered only from the standpoint of hygiene. Its four distinct functions must be duly taken into account; and, in considering the needs of each part of the body, we are to remember that all clothing must try, as far as possible, to conform to the principles illustrated in the perfect coats of so many of the lower animals, coats which are warm, yet perfectly ventilated; close, yet never tight; highly absorbent, yet easily cleansed. It is only by paying attention to these things that dress can be brought into its proper relation to health.

A MODERN POWER HOUSE WITHOUT CHIMNEYS, BOILERS, SMOKE, OR DUST



Courtesy McIntosh & Seymour Corporation

POWER HOUSE OF THE LEHIGH PORTLAND CEMENT CO , IOLA, KANSAS

There are five of these Diesel oil engines, of which three are here shown, of 1000 H P each, which drive direct connected electric generators

POWER FROM LIQUIDS

Utilizing the Vast Stores of Energy
That Are to Be Found in Petroleum

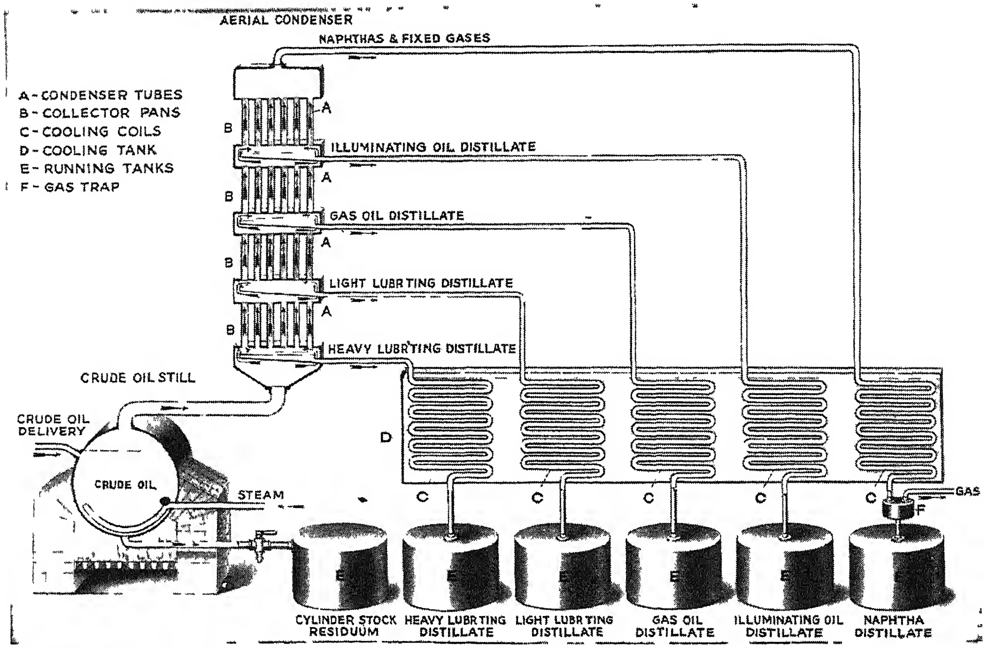
HOW THE DIESEL OIL ENGINE WORKS

PRECEDING chapters have told how solid fuels may be transformed into useful work either by burning them directly under steam boilers, or by passing them through gas-producers and thus transforming them into combustible gas. It remains to consider how power is obtained from petroleum and its constituents and from such liquids as alcohol and other fluid hydrocarbons.

When crude petroleum is heated it gives off compounds of hydrogen and carbon, or "hydrocarbons", as they are commonly called. Coming off as vapors, they are condensed and form gasoline, benzine, naphtha, kerosene, fuel-oil and other liquids of a similar nature. The compounds separate from the crude oil in a regular order according to the temperature applied to it, the lighter gasolines coming away first and the heavier kerosene and fuel oil coming later. After these are separated a still higher temperature is applied and lubricating oils are distilled and condensed. Crude oils vary considerably, depending on the area from which they come, and a great variety of gradations can be made in the products obtained from a given crude oil by altering the temperature of distillation. An accompanying diagram shows in a graphic manner the sequence in which the constituents of crude oil are separated into groups by distillation.

Petroleum and its several products are the best known forms of liquid fuel in this country. Distillates made from wood, and vegetable products of an alcoholic nature have been used with success and no doubt these will be more widely used as crude oil becomes scarcer and dearer. Fuel alcohol can be made from a wide range of vegetable products but as yet it cannot compete with the distillates of crude oil. In Europe benzol, which is a distillate from coal tar, is much used and will, in time, be found of service on this side of the water. All of these liquid fuels contain hydrogen and carbon and, if vaporized and mixed with the proper proportion of air, they burn readily. The lighter kinds, such as gasoline, are so highly inflammable when mixed with air as to be explosive in character, while the heavier compounds burn much less readily and are much more difficult to vaporize.

All liquid, like solid, fuels, must be first converted into vapor or gas before they can be burned in a gas engine. The lighter distillates, such as gasoline, naphtha, etc., are easily vaporized; in fact they will disappear if simply exposed to the air. The heavier distillates, from kerosene down, are more difficult to vaporize and usually require heating to produce this result. Where the liquid fuel is vaporized outside of the engine and fed to it as a gas, the construction of the engine proper and its cycle of operation are usually essentially the same as for any other gas engine. The only difference is in the addition of devices for vaporizing the fuel before admitting it to the cylinder. If the fuel is fed into the engine as a liquid and vaporized inside of it modifications must be made in its constructive features. And in the highest form of heat engine, known as the Diesel type, heavy oils are fed into the cylinder and burned, rather than exploded, the engine working on a somewhat different principle from any of the others.



Courtesy Tide Water Oil Co

FIRST SEPARATION OF CRUDE PETROLEUM INTO GROUPS BY DISTILLATION

We will first consider the use of the lighter distillates which vaporize readily.

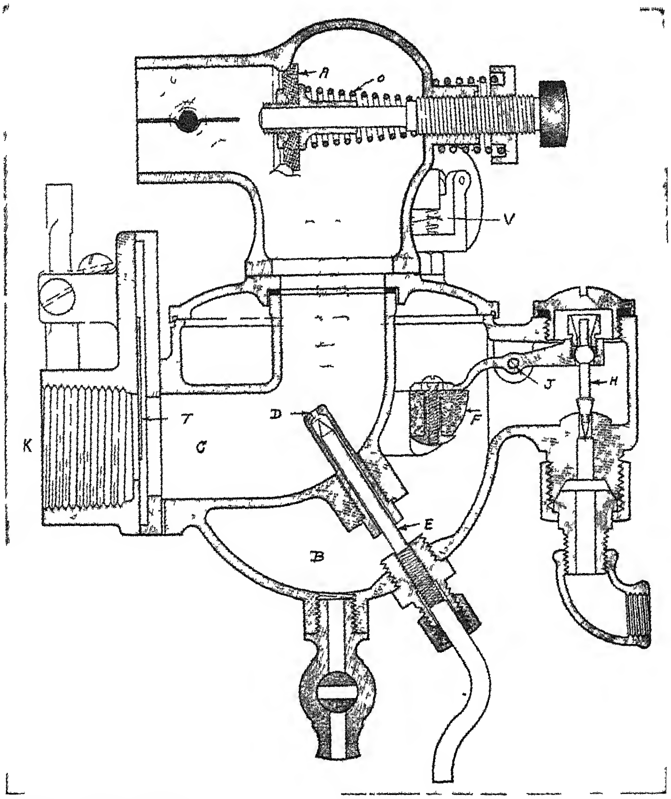
The vaporization of gasoline and the lighter distillates is effected by bringing a current of air, that is on its way to the engine cylinder, into contact with the fuel. A given amount of air will pick up a certain amount of gasoline depending upon the temperature and humidity of the air and the temperature and quality of the gasoline. A larger amount of the lighter and more volatile gasoline will be absorbed by a given amount of air than will be the case with the heavier varieties. When the air has taken up a charge of gasoline the latter is said to be "carbureted" and the apparatus for facilitating this action is called a "carburetor". The term is usually applied to apparatus for carbureting the lighter distillates, the similar apparatus for performing the same function for heavier oils being known as a "vaporizer". It will be clear from the foregoing that the process of vaporization is facilitated by warming the current of air or by warming the fluid to be vaporized. Carburetion or vaporization is not always so simple a process as it appears to be. Gasolines are mechanical mixtures of several components of different degrees of volatility. Care must be taken, therefore, that the method of carburetion used volatilizes all of the compounds and does not leave a heavy residue to be wasted.

The simplest method of volatilizing gasoline is to inject it in the form of a spray directly into the air suction leading to the cylinder. The air carries the gasoline, partly in the form of vapor and partly as a finely divided fluid, into the warm cylinder where vaporization is completed. In such installations the gasoline is forced by a small pump through a little valve, which is controlled by the governor, into the air pipe during the period when the piston is taking in a fresh charge. The pump always delivers the same amount at each stroke and always delivers a little more than is necessary even when running at highest load. The excess gasoline rises in a small vertical pipe and overflows back to the pump, so that the control valve always works under a constant head of gasoline.

Carburetors for large gasoline engines are usually constructed upon similar principles. For instance, the Westinghouse carburetor for such consisted of a vertical cylinder surrounded by a water jacket.

A portion of the warm water leaving the engine jacket passes through the jacket of the carburetor, thus supplying heat. The gasoline is pumped through a pipe to the top of the cylinder and falls as a spray into the interior. The suction of the engine draws a current of air upward through the carburetor, thus taking up and vaporizing the charge on its way to the cylinder. The excess of gasoline is drained off and returned to the suction of the pump.

Nearly all small engines using gasoline are operated by a carburetor. A carburetor of the simpler form is shown in the accompanying illustration, in which the float *F*, hinged at *J*, operates the needle valve *H* permitting gasoline to flow into the chamber *B*. As the gasoline rises in the chamber the float closes the valve and as it falls it opens it. The float automatically keeps the gasoline at a fixed level a little below the outlet of the spray nozzle *D*. The carburetor is connected to the engine cylinder at *K*. As the piston makes a suction stroke a slight vacuum is created in the mixing chamber *C*, causing gasoline to flow past the needle valve *E*. The air rushing in through the air-inlet valve *A* picks up the gasoline and carries it into the cylinder. The flow of gasoline is regulated by the needle valve *E* and the suction by the throttle valve at *K*.

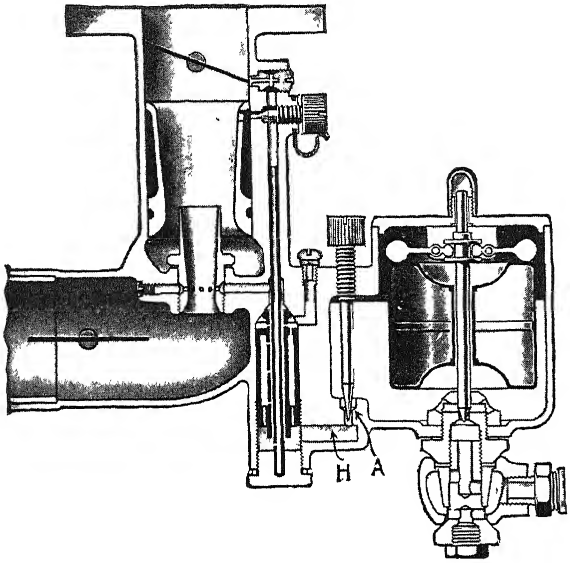


Courtesy Wheeler-Schebler Co

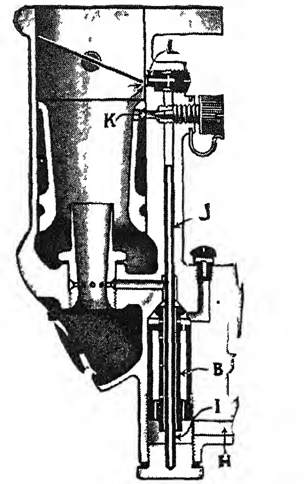
DIAGRAM OF A SCHEBLER CARBURETOR

Carburetors that serve engines which work under widely varying loads are usually fitted with some device for automatically adjusting the air and gasoline supply as the engine changes its load and speed. In the Schebler carburetor the compensating air-valve *A* remains in the closed position shown when the engine is running on low speeds As the speed is increased the partial vacuum in the chamber *C* is increased thus increasing the flow of gasoline and also causing the valve *A* to open against the spring *O*, allowing more air to flow into the carburetor. The tension of the spring and the position of the needle valve are adjusted so that the mixture of gasoline and air are in the same proportion at all speeds By pressing downward on the pin *V*, the float can be slightly depressed, thus allowing the height of the gasoline in the chamber *B* to rise and accelerating the flow of gasoline through the spray nozzle when starting or when a richer mixture is desired.

The Stromberg carburetor, shown on the next page, is more complex. Gasoline is admitted to the main chamber through the float needle valve under control of the float and therefore can reach only a fixed height From the main chamber the gasoline flows under the high-speed needle valve, which is adjusted for highest speeds. The shape of the main air passage is that of a venturi



A, high-speed needle *H*, gas intake.



In the center of the passage *B* is located a tube *J*. When the throttle is closed gasoline is drawn in through hole *I*, mixed with air taken in at *K* and discharged through the idling jet *L* with the highest degree of atomization, due to the fact that a vacuum of more than eight pounds exists above the throttle when the motor is idling.

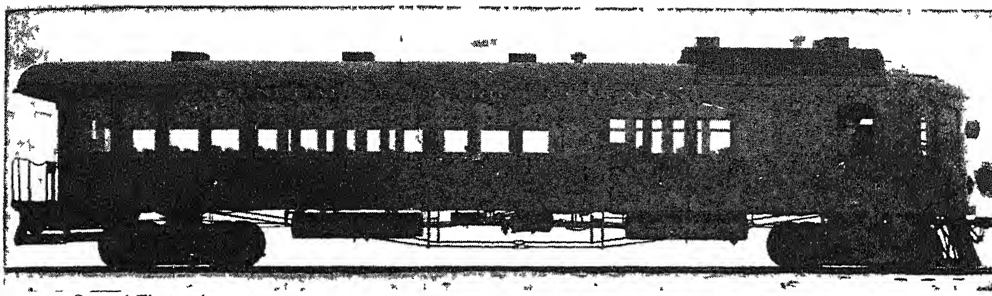
SECTIONAL VIEW AND DETAIL OF STROMBERG "PLAIN TUBE" CARBURETOR

With motor at rest. With motor idling.

tube which has the property of forming a partial vacuum in the air column at the point where the small openings are shown in its walls. These openings are connected to the air "bleeder", so-called. When the engine draws air through the main passage, the vacuum sucks a tiny jet of air through the bleeder and through the gasoline channel, thereby breaking up the gasoline into a fine emulsion in which form it issues through the small holes into the venturi tube. When the air bleeder is properly adjusted a constant proportion of air and gasoline is furnished at all speeds. When the engine is running on slow speeds the high-speed needle supplies more gasoline than is needed. This collects in the accelerating well which surrounds the main gasoline passage and is connected to it by small openings. When the engine is suddenly speeded up this well furnishes a reserve supply for such emergencies. When the motor is running idle with the throttle closed a very strong vacuum is created just above the throttle. This causes a small amount of gasoline to rise in the small central tube of the second figure, and passing under the idle adjustment needle it receives air from an opening into the main tube. The mixture is discharged just at the lip of the throttle and is sufficient to keep the motor running under no load. It will be seen that carbureting devices are highly developed mechanisms and are the result of much study and patient experimentation. Considering their complex construction and the smallness of the passages and controlling parts, their reliability is surprising.

Gasoline is in many respects the most convenient form of fuel yet discovered. It is, of course, very inflammable, but people have learned how to handle it with safety. The gasoline engine using a carburetor is the most convenient source of power for many purposes and it is now a very highly developed and reliable machine. It has placed power within the reach of many people, like the farmer, who have long needed such assistance, and the list of its applications is ever growing. As used for automobiles it ranks as one of man's greatest achievements in overcoming distance, and in its more spectacular use for aviation it is a marvel of lightness for the power that it develops.

In many towns and cities busses driven by gasoline engines have replaced street cars powered by electric motors. Locomotives driven by gasoline engines have been used, but only to a limited extent; they



Courtesy General Electric Co

GASOLINE-ELECTRIC PASSENGER CAR

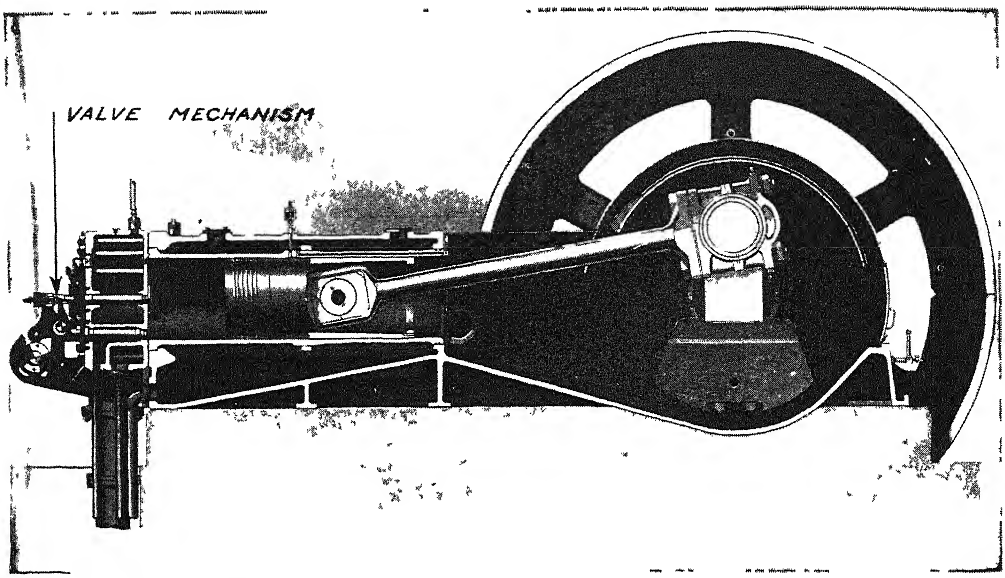
In this model, electric power was generated by a gasoline engine connected to an electric generator. The power operated the electric motors that were placed on the driving trucks.

have also served in various lines of industry. An innovation that was introduced to the general public some years ago was the gasoline-electric passenger car. In this vehicle a powerful gasoline engine was used to operate an electric generator; the electricity that was generated in this way powered the motors that turned the wheels of the car. This model, which has become obsolete, was the forerunner of the Diesel-electric locomotive.

The problem of vaporizing kerosene and other heavy oils is more difficult than that connected with gasoline. The most obvious method follows the idea of the carburetor already described and vaporizes the oil in an external vaporizer before it goes to the cylinder. As has been noted, these heavier oils must be heated before they will vaporize readily. An external vaporizer, therefore, is usually a receptacle of some kind heated by the exhaust gases of the engine and so arranged that the heat thus obtained is applied to the oil to be vaporized. The process of vaporization is somewhat different from that of carburetion and more closely resembles boiling, the mixing of the air necessary for explosion taking place after vaporization. In some vaporizers the oil is dropped at the desired rate upon a hot plate from which the incoming current of air carries off the vapors.

Courtesy J. D. Tate Co.

GASOLINE LOCOMOTIVE DRAWING BALED SISAL GRASS TO A WAREHOUSE IN YUCATAN



Courtesy De La Vergne Machine Co

VERTICAL SECTIONAL VIEW OF DE LA VERGNE OIL ENGINE

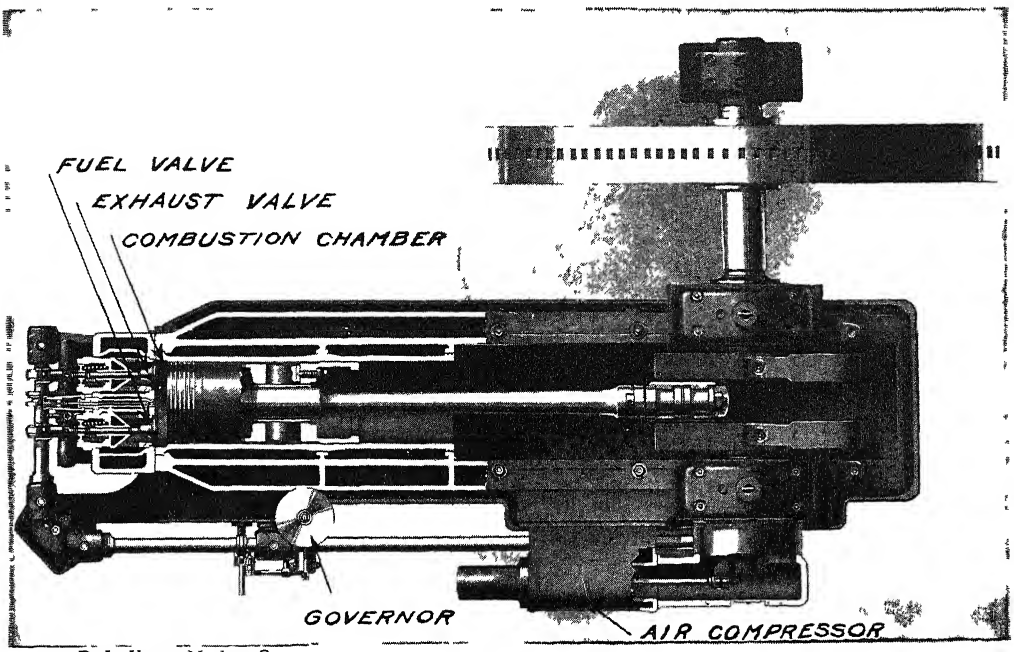
Showing valves and actuating mechanism

External vaporizers which are heated by the engine exhaust must be warmed up by auxiliary means when starting up. All vaporizers are difficult to maintain at the proper temperature. The vaporization of the heavy oils also leaves deposits of carbon which are bothersome.

There is an increasing tendency to perform the vaporization in an internal vaporizer, which is usually a small chamber connected directly with the working cylinder. One of the first and most successful engines of this type is the Hornsby-Akroyd engine first built in England. The vaporizer is a cylindrical chamber attached to the head of the engine and it is unjacketed. This chamber must be heated by a lamp on starting up, but after the engine is in operation the heat of the explosions is sufficient to keep it hot enough to ignite the charge.

The engine works on the usual four-stroke cycle. During the admission stroke air is allowed to enter the cylinder and a charge of fuel oil, such as kerosene, is forced into the vaporizer. As the piston moves inward it compresses the air into the vaporizer where it mixes with the oil vapor which has been formed, and thus makes an explosive mixture which is ignited by the hot walls of the vaporizer. The proportion of the vaporizer must be properly designed to cause ignition at the correct time The kerosene is forced into the vaporizer by a small pump The governor controls the fuel supply through a by-pass valve by means of which the excess oil is permitted to flow back to the suction side of the pump

It will be obvious that any engine igniting after the manner of the Hornsby-Akroyd is liable to premature ignition. This, and a desire to burn heavier oils has led to marked improvements in this type of engine. The accompanying illustrations show two views of the De La Vergne oil engine which is of a very modern type This engine works on the ordinary four-stroke cycle On the first outward stroke the piston draws in a charge of fresh air. On the backward stroke this air is compressed into the combustion chamber When compression is almost or fully completed a charge of oil is sprayed into the combustion chamber through the fuel valve by a jet of air under heavy pressure which breaks the heavy liquid up into small particles that ignite as soon as they strike the hot walls of the chamber. The resulting pressure drives the piston forward on the working stroke at the end of which it starts a new cycle.



Courtesy De La Vergne Machine Co

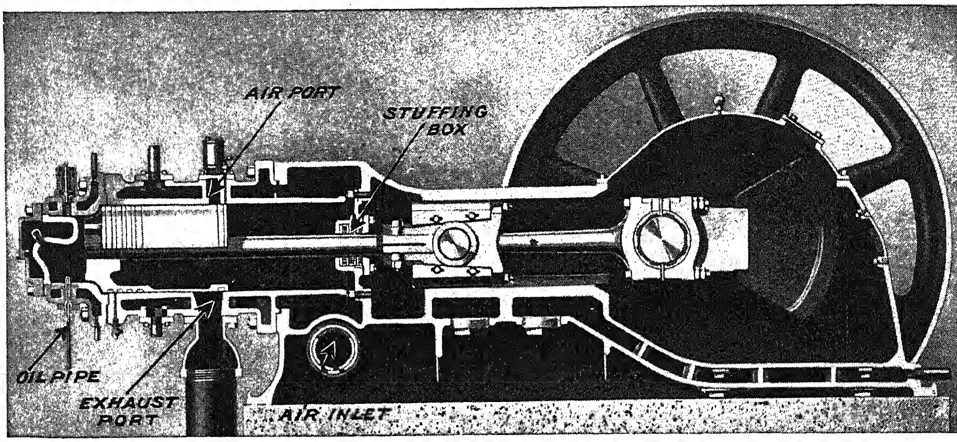
HORIZONTAL SECTIONAL VIEW OF DE LA VERGNE OIL ENGINE

Showing combustion chamber, valves, governor and the air compressor which supplies the fuel jet.

The engine is equipped with a small two-stage air compressor which is driven by a crank from the main shaft. The large piston furnishes compressed air to storage tanks, and this can be used to start the engine. The small piston takes air from the large piston, compresses it still further and supplies the high-pressure air for the oil injection. The governor controls the amount of oil that goes to the injection valve by operating a little valve in the pipe that delivers oil from the oil pump to the sprayer. The air inlet and the exhaust valves are operated by cams on the small shaft across the end of the cylinder which in turn is driven by the shaft which operates the governor.

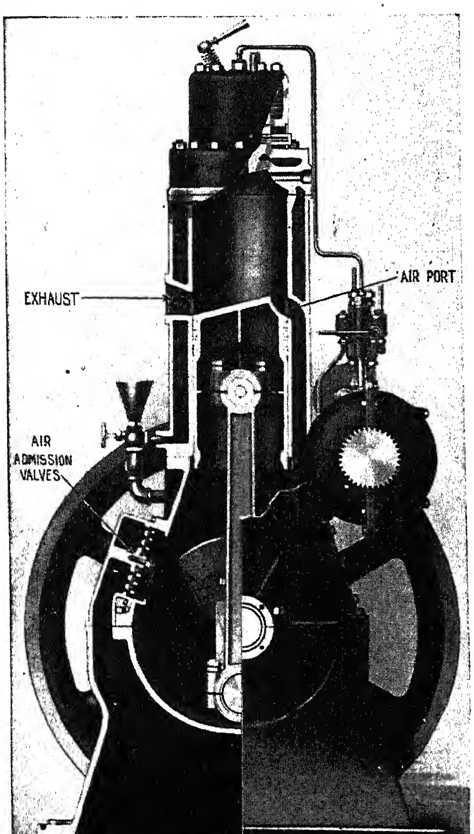
It will be clear that premature explosion cannot occur in this type of engine since no fuel is admitted to the cylinder until the moment of ignition. Now when gases are compressed they become hotter. If the compression is slow, the heat can be readily conducted away, but when it is quick and high enough, and the charge is combustible, the gas may be prematurely ignited. This limits the amount of compression that can be applied in the ordinary gas engine. Where air only is compressed, the compression can be carried higher without danger. The compressive pressure in the De La Vergne engine just described is about 280 pounds, which is much higher than in ordinary engines though not so high as in some other forms of engine to be described later. One of the advantages of this type of engine is the absence of complex electric igniting devices which are such fruitful sources of trouble. They will burn crude petroleum or any of its distillates.

In the chapter on gas engines it was shown that more power could be obtained from a given cylinder if it were operated upon the two-stroke cycle. This applies to oil engines as well. The Bessemer illustrated on the next page is a two-cycle oil engine. The end of the cylinder toward the crank is closed by a head through which the piston rod works in a "stuffing box" to prevent leakage. On the stroke of the piston away from the crank, air is sucked into the crank end of the cylinder through the inlet valve (which is operated by an eccentric on the main shaft so as to be accurately timed in its action), and compressed in the combustion chamber.



SECTIONAL VIEW OF BESSEMER TWO-CYCLE OIL ENGINE

Air only is compressed by the outward motion of the piston in the same manner as the charge of gas and air is compressed in the two-cycle gas engine.

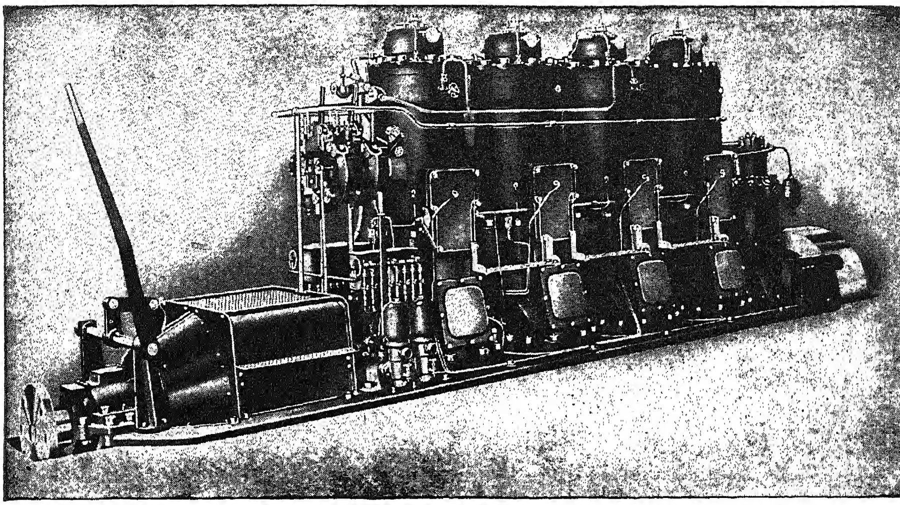


SECTIONAL VIEW OF ANDERSON TWO-CYCLE OIL ENGINE

The crank case forms a reservoir into which the piston compresses air which is used to displace the burnt gases in the other side of the piston and to provide fresh air for the power stroke.

When this is complete the charge of oil is injected and ignited by the hot walls of the chamber. The resultant pressure starts the piston toward the crank in an impulse stroke and at the same time compresses the air in that end of the cylinder to four or five pounds to the square inch. When the piston nears the end of its stroke it automatically opens the exhaust port and shortly after the air port, permitting the compressed air in the crank end to rush into the working end of the cylinder, driving out the burnt products of combustion. On the next stroke this air is highly compressed and the cycle is repeated. It will be seen that the two-cycle oil engine is not open to the objection sometimes made to the two-cycle gas engine, that fuel is liable to leak out of the exhaust port when it and the delivery port from the compression chamber are open at the same time. In the two-cycle gas engine the mixture of air and gas is compressed in the compression chamber but in the oil engine air alone is thus compressed and the fuel is added afterward.

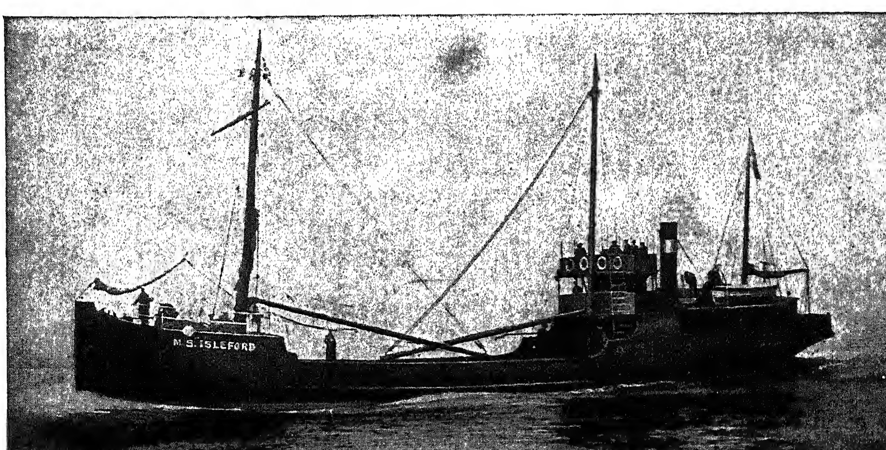
The Anderson oil engine which is here illustrated is also two-cycle. In this engine the air is admitted to the suction chamber by automatic valves which are held against their seats by spiral springs. When the piston creates a partial vacuum in the compression chamber the atmospheric pressure forces the valves downward from their seats and admits air to the chamber.



Courtesy Bolinders Co.
FOUR-CYLINDER MARINE ENGINE OF THE "HOT BULB" OR SEMI-DIESEL TYPE FOR BURNING HEAVY OILS

The general name of "oil engine" has been given to those operating in the manner described. They can burn a wide range of fuel, from crude oil down to some of its lighter distillates. The "fuel oils", so-called, which are distilled from crude oil, after kerosene and before the mineral oils, are much used, and many oil engines burn the crude oil without distillation. They are also called "hot bulb", "hot head" and "semi-Diesel" engines. The significance of the latter name will be clearer after the Diesel engine has been described. Oil engines are proving quite useful for marine work and a large number are now in use on the Pacific Coast where oil is plentiful. The Bolinder Oil Engine Works of Stockholm, Sweden, has installed a large number of two-cycle oil engines as auxiliary power in large sailing vessels and in other craft which are entirely motor driven.

It would not be surprising, in fact, if the success of these auxiliary-powered sailing vessels would give the sailing ship a new lease of life, or result rather in the development of a new type of cargo-carrier, especially in view of the rising cost of coal and the cheapness with which an oil engine can be operated.



MOTOR COASTER PROPELLED BY 320-B. H. P. BOLINDER "HOT BULB" ENGINE

One of the most difficult problems that still confronts engineers and scientists is the transforming of heat into useful work without excessive waste. It has been shown elsewhere that the best steam plant can transform only 16 per cent of the heat of the coal into useful energy and that an ordinary gasoline engine can not transform much more than 20 per cent The steam engine is notoriously wasteful because of the losses incident to heating the working medium. Gas engines working on producer gas have somewhat the same disadvantages due to losses in manufacturing the gas.

Many years ago a great French scientist, Sadi Carnot, pointed out that if a heat engine could be made to operate on a particular cycle of operation it would transform heat into work as efficiently as it is possible to do. The "Carnot cycle", so-called, has ever since set a standard of performance which has never been attained by any actual engine. The ordinary steam engine and the gas and gasoline engines that have been described work in cycles that are largely the result of necessity; for the problem of embodying a theoretic cycle in an actual machine is a difficult task. While both steam and gas engines have been greatly improved mechanically and some improvements made in their thermodynamic cycles, there is still considerable waste in their operation. Engineers are still working on the problem of reducing this waste to the minimum.

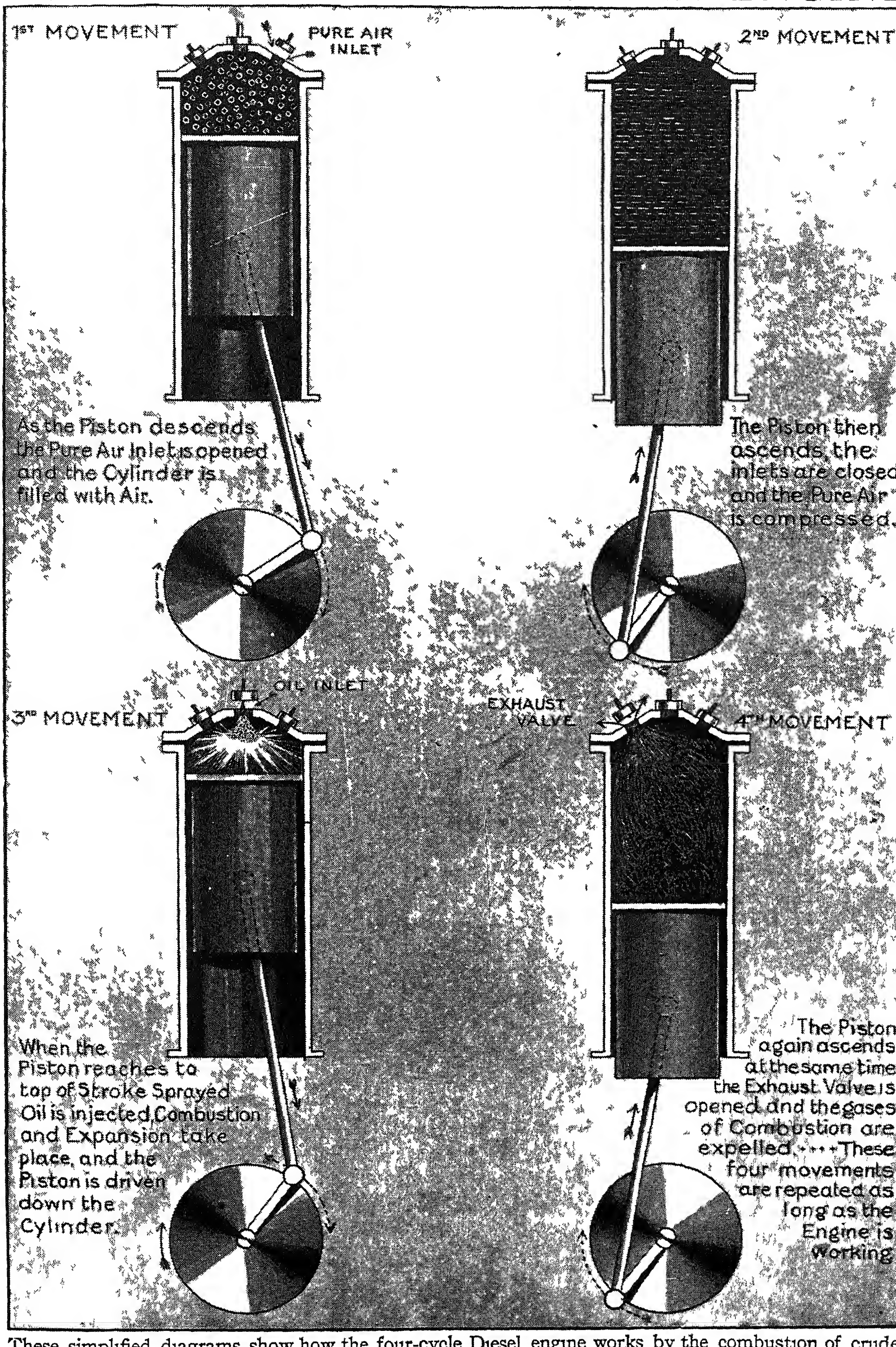
In 1893 Rudolf Diesel (1858–1913), a young German, published a book entitled "The Theory and Construction of a Rational Heat Motor" in which he gave an outline of an astonishingly original engine which would follow the Carnot cycle. Diesel presented his ideas with such force and clearness that several German manufacturers put at his disposal facilities for building an experimental engine. This engine was completed in 1897 and although Diesel did not quite succeed in embodying in it the complete Carnot cycle, it proved to be a great advance over any heat engine that had ever been constructed and it laid the foundation for the building of a new type of heat motor.

The cycle of the Diesel engine resembles that of the Otto four-stroke cycle and in order to understand the reasons for its greater economy it is necessary to know something of the principles of the Carnot cycle. Carnot pointed out that in his ideal cycle the working medium (which is usually air) was to receive all of its heat at the highest temperature of the cycle. This is analogous to the reasoning that for a given quantity of water a water-wheel will be more efficient if all the water falls from the highest available point rather than from a series of different heights. In the ordinary gas engine the heat is applied more or less in the last manner. When a charge of gas is exploded in one of these engines there is a great rise of temperature and pressure so that heat is applied at different levels. In reality the gas engine is not an *internal combustion* engine, as it is usually called, but an *explosive* engine.

Diesel first set himself, therefore, to solve the problem of a high initial pressure and temperature of the working medium. Up to this time all gas engines compressed a charge of gas and air and exploded it by some one of the means that have been described. It has already been noted that gases become hot when compressed and this characteristic prevents the compression of explosive mixtures to any great degree, and engines which work on this principle are limited to a low initial compression, the final maximum working pressure being obtained by the explosion. Diesel was the first to grasp the idea of compressing the air alone up to a very high initial pressure and then injecting the fuel into the cylinder.

In a true Diesel engine the compression stroke carries the air pressure up to about 600 pounds to the square inch, at which the air is so hot that the heaviest crude oils are instantly and very completely consumed without the need of any ignition device. Having obtained the desired pressure by compression, it is not necessary to feed the fuel fast enough to create an explosion, but simply to maintain the pressure on the piston until it reaches the point where the fuel supply is cut off and expansion of the charge begins.

HOW AIR AND OIL DRIVE AN ENGINE



These simplified diagrams show how the four-cycle Diesel engine works by the combustion of crude oil in compressed air, no firing spark being needed as in the ordinary gasoline engine

How the Diesel engine can be made to operate on the two-cycle plan

The full cycle of operations of the Diesel engine then is as follows. On the first outward stroke the cylinder takes in a full charge of air. On the return or compression stroke this air is compressed to about 600 pounds to the square inch. As the crank turns the center and the piston starts outward again, the fuel oil is sprayed into the highly compressed charge of air where it burns, keeping up the pressure until the fuel valve closes. The charge of gas and air now expands as in the ordinary engine. At the end of the expansion stroke the piston moves inward again, sweeping out the burnt gases, and then moves outward starting on a new cycle.

It will be clear from the description of two-cycle oil engines of the simpler types that the Diesel engine can be made to operate upon a two-cycle plan. To do this an extra pump or "scavenging" cylinder must be arranged as in these simpler engines. When the piston is about to start the stroke that normally drives out the spent gases in the four-stroke cycle, the scavenging pump forces fresh air into the cylinder driving out the spent gases. The exhaust valve now closes and the piston compresses the air during its inward stroke and ignition takes place as usual.

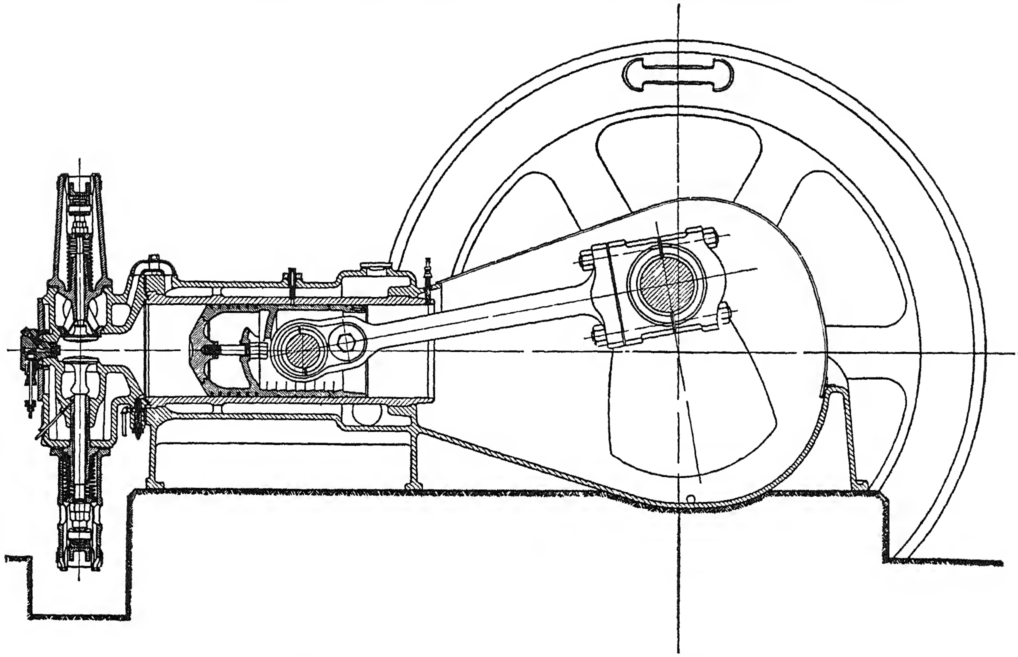
The difference between the true Diesel and the semi-Diesel engine should be noted. In the semi-Diesel, or "oil" engines, that have been described the air is compressed to not more than 300 pounds to the square inch and ignition must be assisted by the hot walls of the combustion chamber. In these engines the entire charge of fuel is injected at once into the compressed air causing an explosion and a rapid rise of pressure to several hundred pounds, depending upon the compression pressure, exactly as in the ordinary gas or gasoline engine. In the Diesel engine the heat of compression is always sufficient to ignite the fuel, and there is no rise of pressure or temperature as the fuel is fed in. All heat is therefore supplied at the highest temperature and as a consequence is much more effective in doing work.

In his original plans Diesel expected to burn powdered coal as well as liquid fuel in his engine. So far no success has been met with in burning solid fuels, but a wide range of heavy fluids have been successfully utilized. The thick residual oil left after extracting the lighter products from petroleum, tar and tar-oils which are by-products of coke manufacture, and waste hydrocarbons which come from other processes, are easily burned. Vegetable oils and oils made from nuts, some of which have little commercial value, make excellent fuel, and the Diesel engine will work with the lighter gasolines and other light hydrocarbon oils, but gaseous fuel is not well adapted for it.

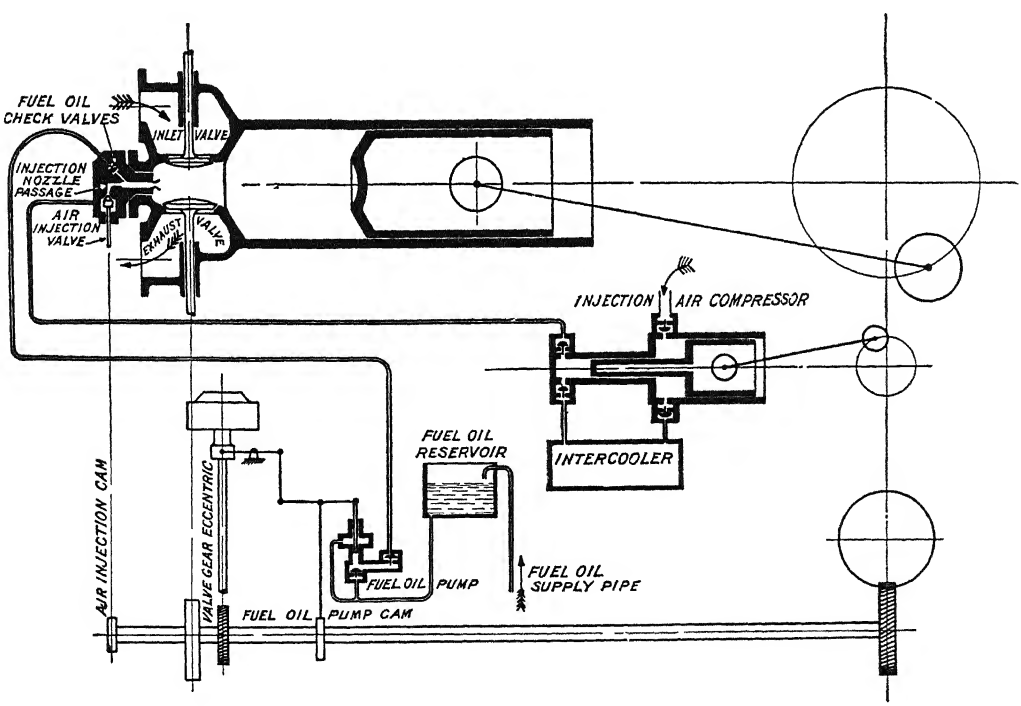
The Diesel engine not so simple mechanically as theoretically

The Diesel engine while quite simple in theory is not so simple mechanically. The charge of oil is delivered to the spray nozzle during the suction stroke when there is little or no pressure in the cylinder. As the amount of oil needed for each cycle is little, this means a very small pump — which is a somewhat bothersome problem in small engines. When compression begins a check valve closes the oil-delivery pipe thus protecting the pump against the high pressures. The oil is forced through the spray nozzle into the cylinder by a jet of compressed air thereby breaking the fuel up into a fine spray. The compressed air must necessarily be at a pressure well above the compression pressure. Since the latter must be from 500 to 600 pounds per square inch the injection air must be furnished at a pressure of from 700 to 900 pounds to the square inch. It is supplied by an air compressor which is driven from the main shaft by a crank or an eccentric. Not only does it require considerable power to operate the compressor but it must be kept cool by a water-jacket because of the heating of the air under compression. Diesel engines are usually provided with an independent air tank into which the air compressor forces air until a pressure of several hundred pounds is reached. This stored air is used to start the engine. The accompanying diagram shows the cycle of an Allis-Chalmers engine of this type.

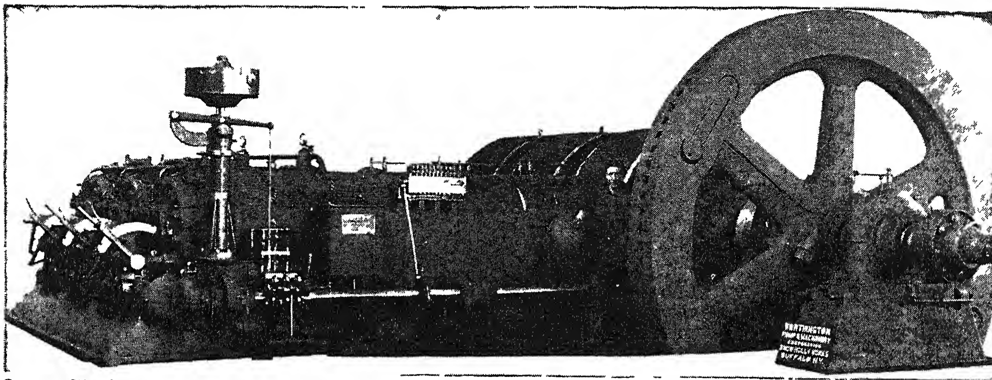
OIL ENGINE STARTING ON STORED AIR



LONGITUDINAL SECTION THROUGH THE ALLIS-CHALMER OIL ENGINE



SCHEMATIC ARRANGEMENT OF THE ALLIS-CHALMERS OIL ENGINE



Courtesy Worthington Pump & Machinery Corp

SNOW THREE-CYLINDER, 600-H P DIESEL ENGINE WHICH WILL BURN VERY HEAVY OIL

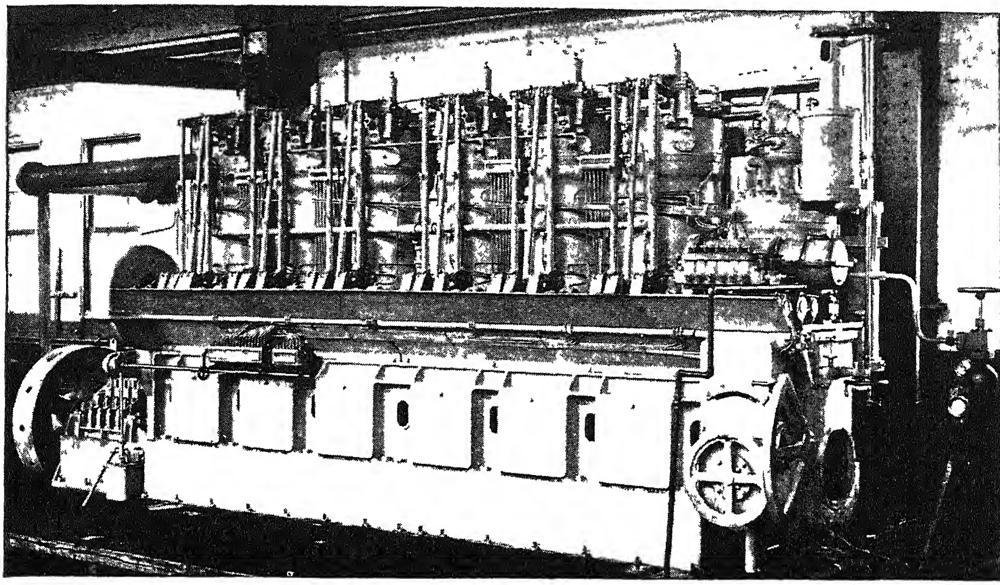
The vertical standard on the left is the inclosed governor which controls the speed of the engine by regulating the supply of oil.

The Diesel engine, unlike the ordinary gas or gasoline engine, requires a skilled engineer. It is also much more expensive to manufacture. But, notwithstanding these objections, it can compete successfully in many places especially when crude oil or some of the by-products that have been mentioned are available, because it is so much more efficient than any heat engine of other type.

The ordinary steam engine can transform from 8 to 10 per cent of the heat of the coal into useful work, the best type of steam plant can transform from 10 to 15 per cent. The ordinary gas or gasoline engine has a corresponding efficiency of from 15 to 20 per cent and a good suction producer plant one of from 18 to 23 per cent. The Diesel engine, however, in spite of its extra pumps and auxiliary mechanism can convert 32 to 35 per cent of the heat units in the fuel into actual work. This high efficiency led to the belief when the Diesel engine first appeared that it would soon drive all other forms of heat engines out of service. Such however, has not been the case. The prophecies were based upon the assumption that the steam engine had reached its highest development. Since the invention of the Diesel engine, however, boilers have been constructed to carry much higher pressures and to burn crude oil and many kinds of cheap fuel. The development of the steam turbine, especially in large sizes, combined with these improvements in boiler construction has given the steam engine a new lease of life.

And it should be remembered that the cost of power is controlled by a number of factors. In places where coal is cheap and crude oil expensive the Diesel engine has no chance against even a poor steam engine. On the other hand, in Texas and California where crude oil is cheap and coal expensive, the Diesel engine can monopolize a large part of the field. Where blast-furnace gas is available the large gas engines that have been described in another chapter can compete against either oil or steam engines. The cost of fuel, the cost of the engine, the reliability of service required and other factors, must all be considered in selecting a power plant and it will probably be some time before the steam engine is in danger of disappearance, though for small powers, particularly where skilled service is not available, the gas and oil engine has practically driven out the small steam engine.

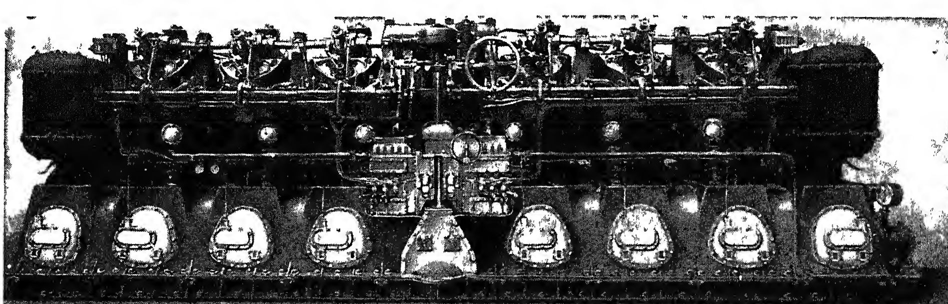
In general it may be said that for small powers and intermittent service the gas and gasoline explosion type of engine has control of the field. For somewhat larger powers where the work is fairly continuous the oil engine of the hot bulb or semi-Diesel type is making rapid headway though a new form of steam engine known as the "unaflow" type is attracting much attention in these moderate sizes. Above 20 H. P. the Diesel engine and the suction gas engine and producer enter the competition. For very large installations steam turbines have come into favor, though fairly large gas engines working on smelting-furnace gases have proved very successful.



A 500-H. P. MARINE DIESEL OIL ENGINE BUILT BY THE McINTOSH & SEYMOUR CORPORATION
These will reverse as easily and as quickly as a steam engine and have proved very reliable in service

At the present time many Diesel engines of from 1000 to 2000 H. P. are in actual operation. Gas engines as a rule do not exceed 400 or 500 H. P., if the large engines operating on furnace gases are left out of consideration. There is every reason to believe, however, that Diesel engines will soon be built in very large sizes, particularly for marine work for which from the very first they were recognized as being particularly well adapted.

Of course, in the beginning, owners and engineers were cautious regarding the new engine, though so much was claimed for it. A number of comparatively small vessels were successfully equipped with the new motor and a number of installations were made in sailing vessels as an auxiliary aid in calm weather. About 1911, however, the 10,000-ton cargo ship *Selandia* was equipped with two 8-cylinder Diesel engines of 1250 H. P. each. The vessel was an unqualified success. Since that time 2000 H. P. in a single multi-cylinder marine engine is not uncommon. It may be said, therefore, that ships up to 15,000 tons driven by Diesel engines are an assured accomplishment. A few builders are prepared to go to larger sizes and the Krupp works in Germany has already constructed an experimental engine with one cylinder that developed over 2000 H. P. and it is reported that this firm has also constructed a 6-cylinder marine engine that developed 12,000 H. P. We may look forward with some confidence to seeing Diesel engines in marine work that will compare with the largest steam units now in that service.



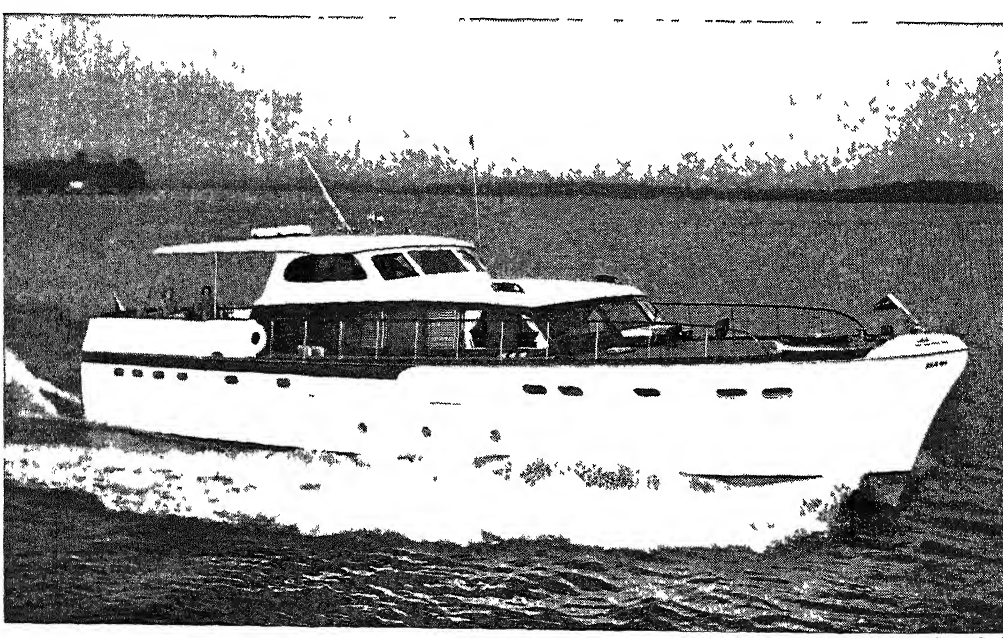
A 1000-H. P. SIX-CYLINDER DIESEL OIL ENGINE BUILT FOR A GERMAN SUBMARINE BY KRUPP

The advantages of the Diesel engine for marine work are obvious. Comparatively few men are required to operate a Diesel installation, even on a large ship; the low-cost fuel that is used results in economy of operation. The use of Diesel engines saves a good deal of space and weight on shipboard, because enormous boilers are not necessary. Obviously, the danger of boiler explosions is eliminated. In warships, the use of Diesel engines does away with telltale smoke. Besides, the Diesel engine, like all internal-combustion motors, can be started in a few minutes, while it takes much longer to get up steam from cold boilers—an important consideration when even a few minutes' delay may mean disaster.

Because of such advantages as these, Diesel engines are used in a wide variety of vessels. They have been employed on submarines for years. Formerly these underwater ships used their Diesel engines only when cruising on the surface; when submerged, they were driven by storage batteries. With the development of the "breathing" device known as the schnorkel, submarines can now use their Diesel engines at all times. (See Index, under Schnorkel.)

Diesel engines are now being used in great numbers to provide motive power for trains. The Diesel-electric combination is particularly popular. In a Diesel-electric locomotive the powerful engines drive big electric generators. The electricity generated in this way provides abundant power for the motors that actually drive the train; it also furnishes light and heat. Many trucks are powered by Diesel engines; so are considerable numbers of passenger busses. However, efforts to introduce these engines in passenger cars and in airplanes have not been particularly successful. Diesel engines are a good deal heavier than conventional gasoline engines; besides, they are not so flexible.

Diesel engines have many uses besides the ones that we have already mentioned above. They serve the building construction industry: they operate power shovels and air compressors and a great many other machines. They do yeoman service, too, on the farm. On many farms Diesel engines are employed to operate the electric generators that provide power, light and heat; they drive tractors; they also pump water for various drainage and irrigation projects.



Chris-Craft

THIS BEAUTIFUL SIXTY-TWO-FOOT MOTOR YACHT IS POWERED BY TWIN 200-HORSE-POWER DIESEL ENGINES. THE YACHT HAS SLEEPING ACCOMMODATIONS FOR AS MANY AS THIRTEEN PERSONS

Science in Revolution (1765-1815) II

by JUSTUS SCHIFFERES

THE REVOLUTION IN CHEMISTRY

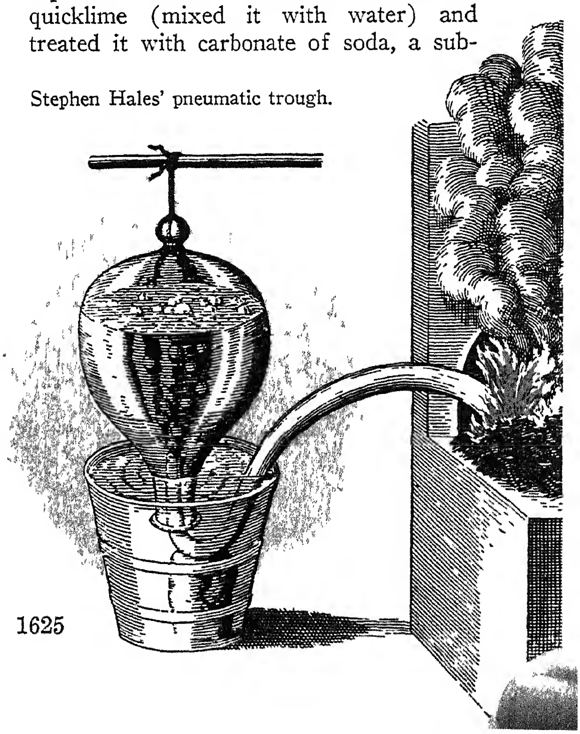
IN the last decades of the eighteenth century, the science of chemistry made such rapid and substantial progress that this was truly a time of chemical revolution. Invalid old ideas were overthrown and new ideas were firmly established. This remarkable advance was due to patient investigators who succeeded in collecting, identifying, weighing and describing certain important gases. Among other things, they succeeded in establishing the difference between "gas" and "air"; they proved that the air that we breathe is composed of several gases, of which oxygen and nitrogen are the most important. The new methods and techniques that were introduced in the course of these researches made chemistry a true science.

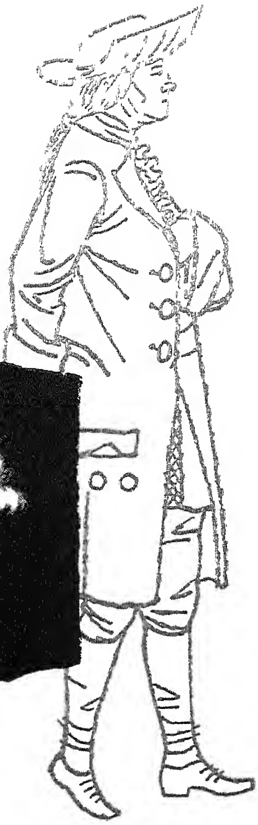
An essential tool in the chemical research of the late eighteenth century was the pneumatic trough, an apparatus for collecting gases. It had been developed in the earlier part of the century by the English clergyman, chemist and physiologist the Reverend Stephen Hales, discussed earlier. In Hales' pneumatic trough gases were led through a pipe from the retorts in which they were heated into a water-filled vessel that was inverted over water (see diagram on this page). Gases are still collected in much the same way over water (or over mercury, in the case of gases that are soluble in water). The huge cylindrical gas houses in our cities are really pneumatic troughs, in which gas is trapped over water.

An important milestone in chemical research in the eighteenth century was the identification of carbon dioxide (CO_2), the gas that is still used in carbonated beverages. This gas was called "fixed air" by its discoverer, Joseph Black (1728–99), professor of medicine and chemistry at the University of Glasgow. Black reported his discovery in 1756 in a paper entitled Experiments upon Magnesia Alba, Quicklime and Some Other Alkaline Substances. The original object of his experiments was to find an alkali milder than the much advertised calcined snails for treating stones in the kidney and bladder. The result of Black's experiments, however, were more far-reaching than he had imagined possible.

By heating chalk, he decomposed it into quicklime and carbon-dioxide gas. He showed that chalk loses weight when it is heated in air, because carbon dioxide escapes into the air. Black now slaked the quicklime (mixed it with water) and treated it with carbonate of soda, a sub-

Stephen Hales' pneumatic trough.





HENRY CAVENDISH

JOSEPH BLACK

stance containing carbon dioxide. The carbon dioxide combined with the quicklime and the product was — chalk! In other words, Black had decomposed a substance into two entirely different ones, and then, recombining these two, had reproduced the original substance.

Black's paper marked the first detailed study of a chemical reaction. He had discovered a gas different from air — "fixed gas," or carbon dioxide. He had shown that it could exist free or else combined with other chemical substances; he had succeeded in transferring it from one chemical compound to another; he had discovered that it had its own particular properties.

Black was a pioneer in physics as well as in chemistry. He was one of the first to distinguish between temperature and heat — that is, between intensity of heat and quantity of heat. He also developed the concept of latent heat — the extra, hidden quantities of heat that are necessary to turn ice into water or water into steam before the temperature is raised.

A decade after the identification of carbon dioxide, another gas was isolated — "inflammable gas," which we now call hydrogen. Its discovery was announced in 1766 by the Honorable Henry Cavendish, in a paper called Factitious Airs (gases produced in the laboratory). Cavendish was a unique figure in the history of science. He was an exceedingly wealthy, shy, woman-hating philosopher and a chemical experimenter, who has been described as "the richest among the learned and the most learned among the rich." The famous Cavendish Physical Laboratory was endowed by a lineal descendant of Cavendish's uncle and was named in the great chemist's honor.

Cavendish produced hydrogen by dissolving metals (zinc, iron and tin) in strong acids, and he estimated with unusual accuracy how much of the "inflammable air" was evolved by the action of acids on the different metals. Later, in a paper on Experiments in Air, he reported that he had exploded "inflammable air" and "dephlogisticated air" (really oxygen) and had obtained water. He proceeded to calculate the approximate proportions of these two gases in water.

The identification of the gas oxygen

By far the most important of all the gases that were identified in the eighteenth century was oxygen. This element is the commonest to be found in nature; it makes up about one-half of the mass of the globe. In the earth's crust it is in combination with a great many other elements. It is found in the waters of the oceans; one atom of oxygen is combined with two atoms of hydrogen to make a water molecule (H_2O). Oxygen is also contained in the air that we breathe; one-fifth, roughly, of this air is pure oxygen. Not only is oxygen the commonest element in nature, it is also essential for respiration (breathing) and combustion (burning). Furthermore, it combines with other elements to produce such compounds as water and iron rust. All these facts are common knowledge today; but they were unknown until

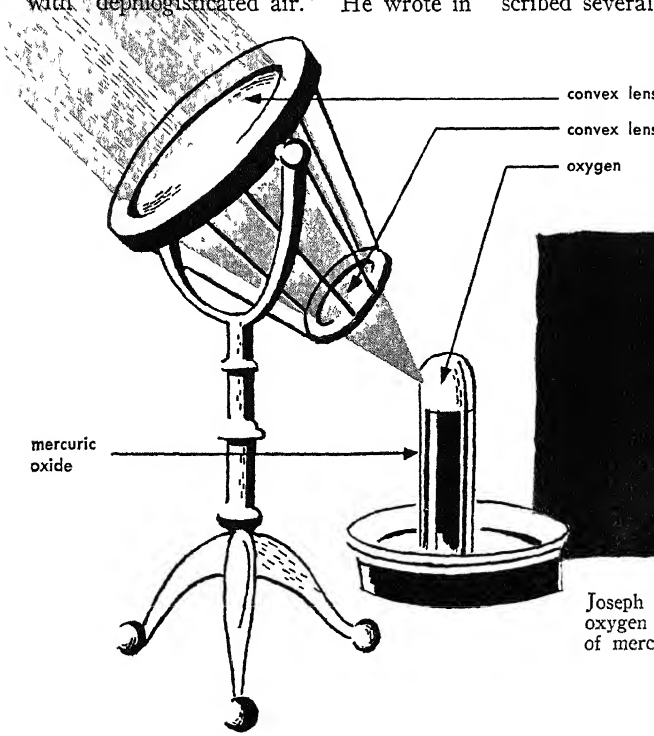
the last quarter of the eighteenth century. We owe the discovery of oxygen to three men — Joseph Priestley, Karl Wilhelm Scheele and Antoine Laurent Lavoisier.

Joseph Priestley (1733–1804) was a vigorous nonconformist English minister, interested in many phases of science. He first produced oxygen in August 1774 by heating oxide of mercury with a strong burning lens some twelve inches in diameter. A firm believer in the phlogiston theory (see the Index), Priestley reasoned that the "phlogiston" had been driven out of the "air" that he had collected in his improved, mercury-filled pneumatic trough; he therefore gave the name of "dephlogisticated air" to the oxygen that he had collected. He was surprised to find that a candle burned in this gas "with a remarkably vigorous flame."

By heating various substances with his burning glass, Priestley had already produced other "airs" in his laboratory — for example, "alkaline air" (ammonia gas), "nitrous air" (nitric acid), "vitriolic acid air" (sulfur dioxide) and "marine acid air" (hydrogen chloride). But none of these, in his estimation, could compare with "dephlogisticated air." He wrote in 1775 that it was "five or six times better than common air for the purpose of respiration, inflammation and, I believe, every other use of common atmospherical air." He found that mice lived longer in "dephlogisticated air than in an equal volume of ordinary air."

Priestley lived a troubled life. His liberal theological and political views made it necessary for him frequently to change his place of residence and his vocation. He was in turn a tutor, a schoolmaster, a literary companion and a clergyman. His happiest and most productive years were passed in Birmingham, where he was a friend of Matthew Boulton, James Watt, Erasmus Darwin and other notables. In 1791, his house in Birmingham was burned by a mob, which had been angered by his avowed sympathy for the French Revolution. Three years later, Priestley emigrated to the United States. He settled at Northumberland, Pennsylvania, and there he remained until his death in 1804.

Another chemist to isolate oxygen was a German pharmacist living in Sweden — Karl Wilhelm Scheele (1742–86). In his Treatise on Air and Fire (1777), he described several ways of preparing oxygen.



Joseph Priestley, who produced oxygen in 1774 by heating oxide of mercury with a burning lens.

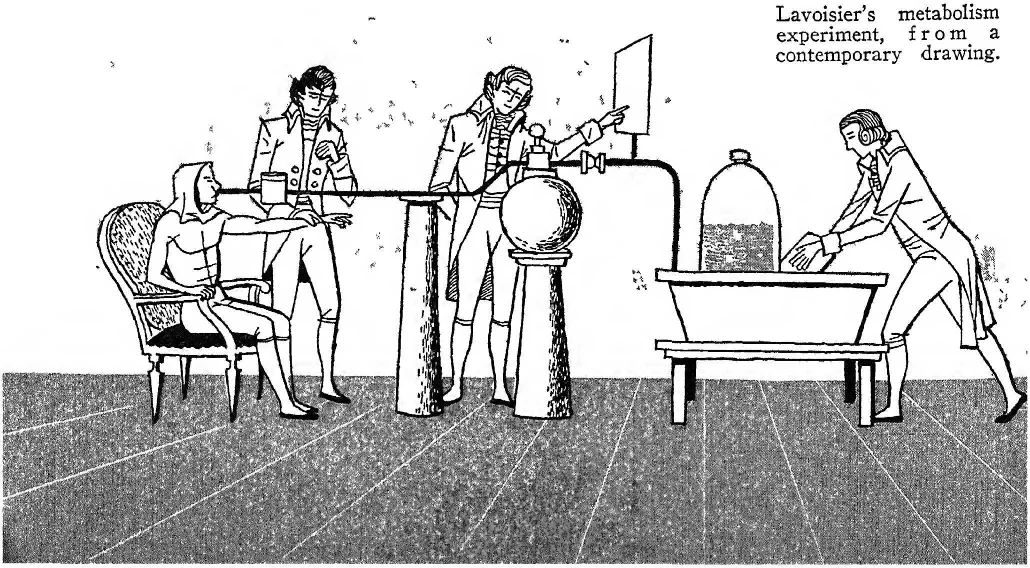
One method was to treat finely ground manganese dioxide with sulfuric acid; he collected the gas formed in this way in a distended bladder. As he did most of his research for the Treatise before 1773, he probably isolated oxygen before Priestley; he called it "fire air" or "empyreal air." In the Treatise on Air and Fire, Scheele also proved that atmospheric air consists chiefly of two different gases: "fire air" (oxygen) and "foul air," or "vitiated air," (nitrogen).

This poor and sadly overworked pharmacist was one of the finest chemists in Europe. He discovered a number of chemical substances, including chlorine, manganese and hydrofluoric acid (which etches glass), glycerol and copper arsenite (also called Scheele's green). Also, he was one of the first to study the effects of light on silver salts, a reaction that is essential to photography.

While Priestley and Scheele had definitely isolated oxygen, their knowledge of its properties was rather scanty. The first man to understand the vital properties and the true significance of oxygen was the French aristocrat Antoine-Laurent Lavoisier (1743–94). Lavoisier proved that in any form of combustion — in burning, in the rusting of metals, in the respiration of animals — the oxygen of the air combines with the materials that are undergoing oxidation. Thus we may call burning a *rapid* oxidation, rusting a *slow* oxidation. Lavoisier's painstaking researches dealt the death blow to the phlogiston theory, which had wrongly maintained that burning caused phlogiston to be released. It was Lavoisier who first used the name oxygen. It means "acid-former"; Lavoisier pointed out that sulfur, phosphorus and other substances produce acids when burned with oxygen in the presence of water.

Lavoisier's contributions to our knowledge of oxygen represent but part of his contribution to the development of chemical science — he has been rightly called the "father of chemistry." He was a man of greatly varied interests and experimented incessantly. For example, he heated water for twelve days in a peculiar kind of vessel called a "pelican" in order to prove the falsity of the belief that water could turn into earth. By burning a diamond he demonstrated that it was only a form of carbon. He repeated the experiment of Cavendish of producing water from the union of oxygen and hydrogen.

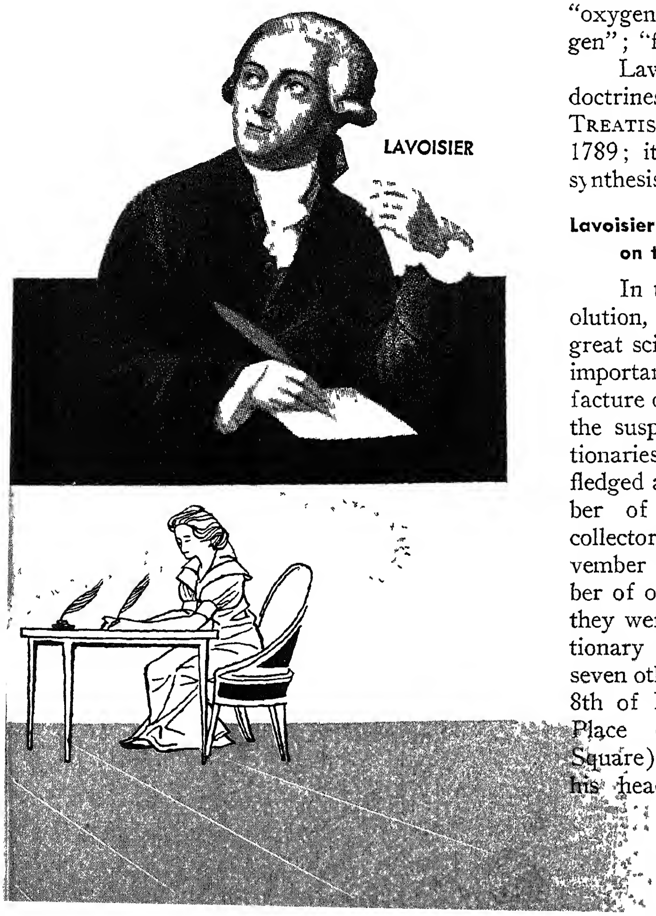
Lavoisier devised ingenious chemical laboratory equipment and, making use of accurate balances and scales, he weighed substances more accurately than they had ever been weighed before. He was the first to state in so many words the principle of the conservation of matter in chemical reactions. "Nothing creates it-



Lavoisier's metabolism experiment, from a contemporary drawing.

self," he wrote. "In every operation, or reaction, there is an equal quantity of matter before and after . . . there is only exchange or modification."

Lavoisier's brilliant mind established once and for all the modern idea of chemical elements. It had been set forth earlier but much more sketchily by Robert Boyle (see the Index). Lavoisier defined elements as substances that cannot be further decomposed by chemical means. He classified all elements known to him in four categories: (1) the so-called "imponderables," light and caloric (that is, heat), and the gases oxygen, azote (nitrogen) and hydrogen; (2) substances that yield acids when combined with oxygen — such as sulfur, phosphorus and carbon; (3) metals that become oxides by combination with oxygen — antimony, silver, arsenic, bismuth, copper, iron, gold and so on; (4) the earths, including lime, magnesia, alumina and silica. Some of the supposed "elements" in Lavoisier's list (such as light, caloric, lime, alumina and silica) are not really elements at all; but he correctly recognized twenty-three bona fide ones.



LAVOISIER

In the year 1787 Lavoisier, in collaboration with the chemists De Morveau and Berthollet, published a treatise on NEW CHEMICAL NOMENCLATURE. This work introduced the system of naming substances according to their chemical composition or properties. Before this time, chemical nomenclature had been most confused. Queer, harsh and mystical names, often holdovers from alchemy, were still in use — such as powder of algaroth, Pampholix, oil of tartar made by the bell, and butter of arsenic. In place of these traditional and inexact names, Lavoisier and his colleagues proposed exact terms, scientifically derived. Thus the term "dephlogisticated air" (also called "empyreal air," "fire air" and what not) was replaced by the word "oxygen"; "inflammable air" by "hydrogen"; "fixed air" by "carbon dioxide."

Lavoisier set forth the new chemical doctrines of his day in his ELEMENTARY TREATISE ON CHEMISTRY, published in 1789; it has been called "the first great synthesis of chemical principles."

Lavoisier dies on the guillotine

In the early days of the French Revolution, Lavoisier, as one of France's great scientists, was entrusted with several important tasks — particularly the manufacture of gunpowder. But he soon aroused the suspicion of the more violent revolutionaries. For one thing, he was a full-fledged aristocrat; he had also been a member of that group of hated revenue collectors known as tax farmers. In November 1792, he was arrested with a number of other tax farmers; six months later they were all sent to trial before a revolutionary tribunal. Lavoisier and twenty-seven others were condemned to die; on the 8th of May they were guillotined at the Place de la Révolution (Revolution Square). "It took but a moment to cut off his head," said the mathematician La-

grange, in bitter comment. "It will take a century to grow another like it."

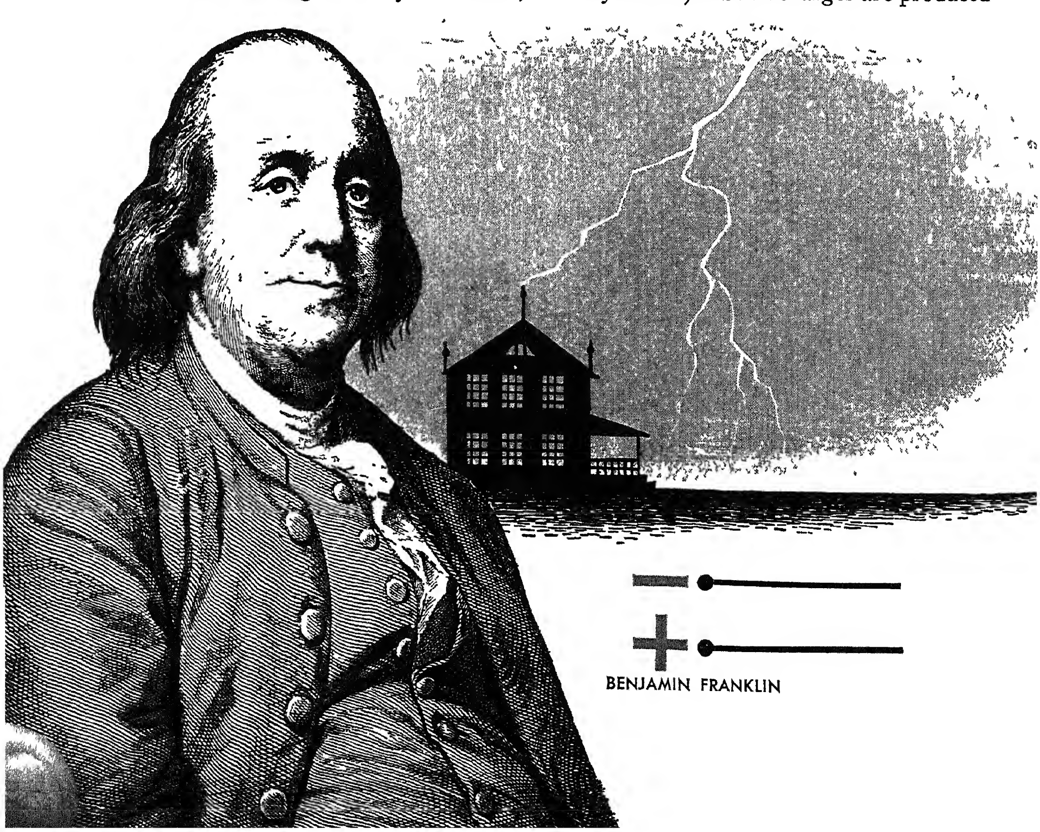
By the end of the eighteenth century the labors of Black, Cavendish, Priestley, Scheele, Lavoisier and their fellow researchers had put the science of chemistry on a firm foundation. It was now recognized that in chemistry, quantitative analysis, which seeks to answer the question "How much?" is as important as qualitative analysis, which is concerned with the qualities, or properties, of substances. Quantitative chemical analysis now came into its own. Its great weapon was the balance — the lever balanced on a knife edge and hung at either end with weighing pans. Its chief article of faith was the conservation of matter — the concept that though substances may be changed, they can neither be created nor destroyed by men.

THE BEGINNINGS OF ELECTRICAL RESEARCH

Even in antiquity it was known that when amber, jet and several other materials are rubbed with fur or cloth, they can attract feathers and other light objects. The Greek philosopher and naturalist Theophrastus, who lived in the fourth century B.C., discussed this phenomenon; so did the Roman scholar Pliny the Elder, who flourished some four centuries later.

In the last years of the sixteenth century Sir William Gilbert, physician to England's Queen Elizabeth I, found, as we have seen, that a good many substances, when rubbed, could attract objects. He called the mysterious property in question "electric force" (from *elektron,* the Greek word meaning "amber"). Gilbert's researches aroused a good deal of interest; a considerable number of persons began to dabble in electrical experiments. But very little came of them until the eighteenth century.

During the greater part of that century, researchers interested themselves in producing charges of static electricity (electricity at rest). Such charges are produced



BENJAMIN FRANKLIN

by friction; the object that is rubbed acquires a charge that stays on it. (Static is derived from the Latin word for stay: *stare.*) You can produce an electrostatic charge by running a rubber comb through your hair; the comb will then attract bits of paper and other light objects.

Probably the first real friction machine for producing an electrostatic charge was constructed by the German Otto von Guericke in the latter part of the seventeenth century. This device consisted of a sulfur sphere mounted on an axle. The sphere acquired an electrostatic charge when a hand was placed upon it as it was rotated. More efficient electrostatic machines were invented later by Hauksbee, Winkler, Watson and Priestley.

The conduction of electricity

In the year 1729 the Englishman Stephen Gray discovered that the electricity produced by electrostatic machines could be transmitted or conducted through various bodies. The ability to conduct electricity, he found, depends upon the material of which a body is composed. Thus, a metal wire conducts electricity very well; hard rubber conducts electricity so poorly that it can be used to insulate electric wiring. The name "conductor," referring to a body that conducts an electric charge, was first used in 1736 by the French inventor Jean-Théophile Desaguliers.

The early electrical experimenters noted that when certain bodies acquire an electrical charge through rubbing, they attract certain charged substances and repel others. In 1734 Charles Du Fay, superintendent of gardens to King Louis XV of France, sought to explain this phenomenon by his theory that there are two kinds of electricity. One kind, he thought, was produced by glass rubbed with silk; he called it "vitreous electricity." (*Vitrum* means "glass" in Latin.) He gave the name of "resinous electricity" to that produced by resin rubbed with wool or fur. (Amber is really a fossil resin.) "The characteristics of these two electricities," he wrote, "are such that a body of the vitreous electricity, for example, repels all such as are of the same electricity, and on the contrary, attracts all those of the resinous electricity." Since electricity was considered to be a kind of fluid, Du Fay's theory became known as the two-fluid theory of electricity.

Another sensational discovery—which heightened popular interest in electricity at this time — was the so-called Leyden jar, which stored static electricity (see page 372). It was sometimes referred to as "Mr. Musschenbroek's wonderful bottle," after the name of one of its co-discoverers. This apparatus is essentially a glass bottle or jar, lined inside and out with tin foil or lead. Its virtue is that it can store great quantities of static electricity, "condensed" in the nonconducting glass sandwiched between two conducting metal sheets. It is, in fact, an electrical condenser, such as we find, in a much different design, in any radio or television set. The Leyden jar can be heavily charged with electricity, and the charge can be released with shocking effect.

The original type of Leyden jar was developed independently in 1745 by the Dutchman Pieter van Musschenbroek and the German Ewald Georg von Kleist. The name "Leyden jar" is derived from the Dutch city of Leyden, where Musschenbroek performed the experiments that led to the invention of the apparatus. The startling effects that were produced by the Leyden jar aroused popular and scientific interest in many different lands — in Russia and in America, among other places.

A renowned American experimenter, Benjamin Franklin (1706–90), now entered upon the scene. Franklin was one of the most versatile men who ever lived. He was an outstanding newspaperman, printer, bookseller, author and diplomat; he was the inventor of bifocal spectacles, the Franklin stove, the lightning rod and a flexible catheter (a tubular instrument for drawing off urine from the bladder). Franklin was also greatly interested in medicine. He wrote one of the best descriptions of lead poisoning, a disease of the print shop; he was the principal founder

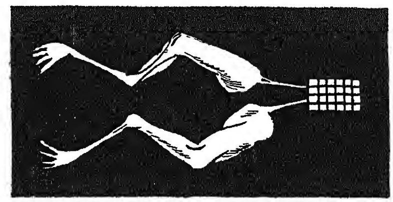
and the first president of the Pennsylvania Hospital.

The scientific reputation of this remarkable man rests chiefly on his work in the field of electricity, in which he distinguished himself as an experimenter and a theorist. For him electrical experiments were at once a rewarding scientific discipline and a fascinating pastime. In a letter written in the summer of 1749 to Peter Collinson, a London merchant, he said: "Hot weather coming on, when electrical experiments are not so agreeable, it is proposed to put an end to them for this season, somewhat humorously, in a party of pleasure on the banks of the Skuylkil [Schuylkill River, in southeast Pennsylvania]. A turkey is to be killed for our dinner by an electrical shock and roasted by the electrical jack before a fire kindled by an electrified bottle [Leyden jar]; when the healths of all the famous electricians in England, France, Holland and Germany are to be drunk in electrified bumpers, under the discharge of guns from the electrical battery."

Franklin proposed a theory of the nature of electricity that was to be useful for almost a hundred years. Like Du Fay, he thought of electricity as an "imponderable [weightless] fluid, consisting of extremely subtle particles." But he disputed the two-fluid theory of Du Fay. Following the suggestion of the Englishman William Watson, he held that electricity was a single fluid that could move in all directions. He held that even uncharged bodies contained this fluid, which produced no particular effects as long as a normal amount was present. When a body was vitreously electrified, he thought, it contained more fluid than it would normally possess; when it was resinously electrified, it contained less fluid than the normal amount. In either case, however, he believed the same fluid was involved.

Franklin proposed to do away with the terms "vitreous" and "resinous electricity." For "vitreous electricity" he proposed to substitute "positive," or "plus," electricity; for "resinous electricity," "negative," or "minus," electricity. Though Franklin's single-fluid theory has long been abandoned, the terms "positive," or "plus," and "negative," or "minus," applied to electrical phenomena, are still in common use.

In his famous kite experiment, performed in June 1752, Franklin definitely proved that the lightning that flashes in the skies is the same sort of "electrical fire" as that generated on earth in electrostatic



machines. In a letter to his English correspondent Collinson, he described the apparatus he used and the experiment itself as follows:

"Make a small cross of two light strips of cedar, the arms so long as to reach to the four corners of a large thin silk handkerchief when extended. Tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite; which being properly accommodated with a tail, loop and string, will rise in the air, like those made of paper; but this being silk, it is fitter to bear the wet and wind of a thunder gust without tearing.

"To the top of the upright stick of the cross is to be fixed a very sharp pointed wire, rising a foot or more above the wood. To the end of the twine, next the hand, is to be tied a silk ribbon, and where the silk and twine join, a key may be fastened. This kite is to be raised when a thunder gust appears to be coming on, and the person who holds the string must stand within a door or window under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window.

"As soon as any of the thunder clouds come over the kite, the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified, and the loose filaments of the twine will

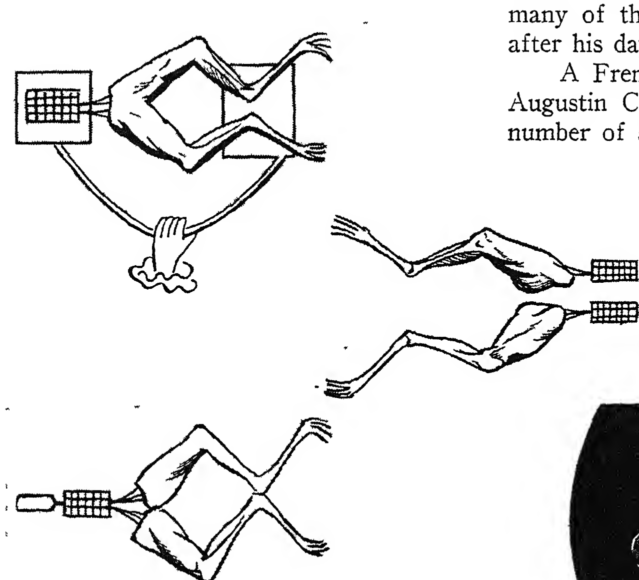
stand out every way, and be attracted by an approaching finger. And when the rain has wet the kite and the twine, so that it can conduct the electric fire freely, you will find it stream out plentifully from the key on the approach of your knuckle.

"At this key the phial [Leyden jar] may be charged; and from electric fire thus obtained, spirits may be kindled, and all the other electrical experiments be performed, which are usually done by the help of a rubbed glass globe or tube [an electrostatic machine], and thereby the sameness of the electric matter with that of lightning can be completely demonstrated."

The demonstration that lightning is an electrical effect completely changed the thinking of many people who had once regarded the blinding glare of a lightning flash with superstitious awe. (See the article called When Lightning Strikes, in Volume 1 of this set.)

Two renowned scientists, whose contributions to chemistry we described in the previous section of this chapter, were greatly interested in electrical phenomena. In 1767 Joseph Priestley, one of the discoverers of oxygen, published a HISTORY OF THE PRESENT STATE OF ELECTRICITY, which summarized all that was then known about electricity — static electricity, of course. Another pioneer in chemical research, Henry Cavendish, performed a great many electrical experiments. Unfortunately he did not publish the results of these experiments, apparently because in his opinion they did not meet the high standards he had set for himself. When his laboratory notes were edited and published by James Clerk Maxwell in 1879, they showed that Cavendish had anticipated many of the discoveries that were made after his day.

A French military engineer, Charles-Augustin Coulomb (1736–1806), made a number of significant contributions to the budding science of electricity. For one thing, he measured the force of attraction between two electrically charged spheres. He did this by means of a torsion balance. In this device, the amount of twist or turn given by such charged bodies is recorded on a scale. Coulomb also investigated the distribution of electrical charges. He



Some of Galvani's classical experiments with frogs' legs. He came to the conclusion (a quite erroneous one!) that "animal electricity," produced within the frogs, made their legs twitch under certain conditions.

LUIGI GALVANI

found that electricity distributes itself all over a conductor, regardless of its shape, but that the charge is concentrated on the outer surfaces and does not penetrate the interior. (That is why the inside of an automobile is a safe place in a thunderstorm.) Coulomb also showed that the density of charge on a conductor is greater where the surface is more convex and less where the surface is more concave; that the greatest density of electrical charge is to be found on a sharp point.

The revelation of current electricity

The earliest known electrical phenomena, which we have so far been discussing, concerned static electricity. In the last decades of the eighteenth century, however, a new kind of electrical phenomenon — current electricity — was revealed, at first through the efforts of two Italians, Galvani and Volta. In current electricity the charge is not concentrated in any one place but flows freely.

Luigi Galvani (1737–98), a lecturer in anatomy in the University of Bologna, engaged in a series of experiments with frogs in the 1770's. To quote his own account: "I had dissected and prepared a frog, and while I was attending to something else, I laid it on a table on which stood an electrical machine at some distance from its conductor and separated from it by a considerable space. Now when one of the persons who were present accidently and lightly touched the inner neural nerves of the frog with the point of a scalpel, all the muscles of the leg seemed to contract repeatedly as if they were affected by powerful cramps."

Galvani was astonished at this phenomenon, and he desired to investigate it. He found that wherever he touched the frog's nerves with the metal part of his bone-handled knife and at the same time someone else drew a spark from an electrostatic machine, the frog's leg twitched. After he had cut up hundreds of frogs to test out his ideas, Galvani came to the conclusion that some kind of "animal electricity," produced within the animal and carried in a "fine, nervous fluid," was the cause of the twitching frogs' legs.

Later he found that when the frogs were hung on an iron railing by means of copper hooks, the muscles of their legs also twitched. He then, in 1786, constructed a "metallic arc" made up of two different metals — one iron, the other brass or silver. When one of these metals was brought in contact with the frog's nerves and the other with a muscle of the animal, the muscle would contract. Galvani came to the conclusion that the muscles moved because of the "animal electricity" within the frog. He reasoned, clearly but quite wrongly, that the external negative electric charge was united with the positive charge arising from the inner substance of the nerve.

Galvani's experiments were repeated by Alessandro Volta (1745–1827), then professor of physics at the University of Pavia and already distinguished for his researches in electricity. At first Volta accepted Galvani's theory of "animal electricity." Further experiments, however, caused him to doubt the theory and then to oppose it violently. He came to the conclusion that when two different kinds of metal are connected through a moist medium, such as a frog's body, they bring about a flow of electricity — an electric current. It was this current, he held, that had produced the twitching of frogs' legs in Galvani's experiments and in his own.

Volta produces an electric current

In the production of electric current, Volta soon found, any moist body could serve as a medium — damp cloth or paper, or the human tongue. He succeeded in producing an electrical effect — a tingling, sour taste in his mouth — by putting upon his tongue at the same time a silver spoon and a piece of copper wire or tin foil connected with the spoon.

Volta was now ready to develop an apparatus, since called a Voltaic pile, for producing an electric current. He prepared a neat pile of alternate discs of zinc (or tin) and copper (or silver), separated by

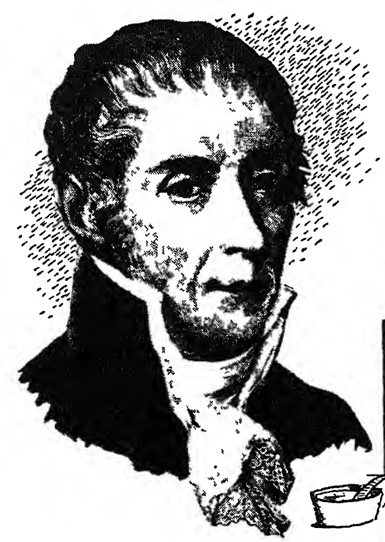
round pieces of cardboard (or leather) soaked in salt water (or lye) and piled up to the number of thirty to sixty like a stack of poker chips. This Voltaic pile represented the first real electric storage battery.

In a letter dated March 20, 1800, Volta informed Sir Joseph Banks, president of the Royal Society of London, that he could also produce electric current with an apparatus that he called "the crown of cups." He wrote: "We set up a row of several cups of wood, of shell, of clay, or, better, of crystal (small drinking glasses or goblets are very suitable), half full of pure water, or, better, of brine or of lye. We join them all together in a sort of chain by means of metallic arcs, of which one arc is copper or silvered copper and the other tin, or, better, zinc."

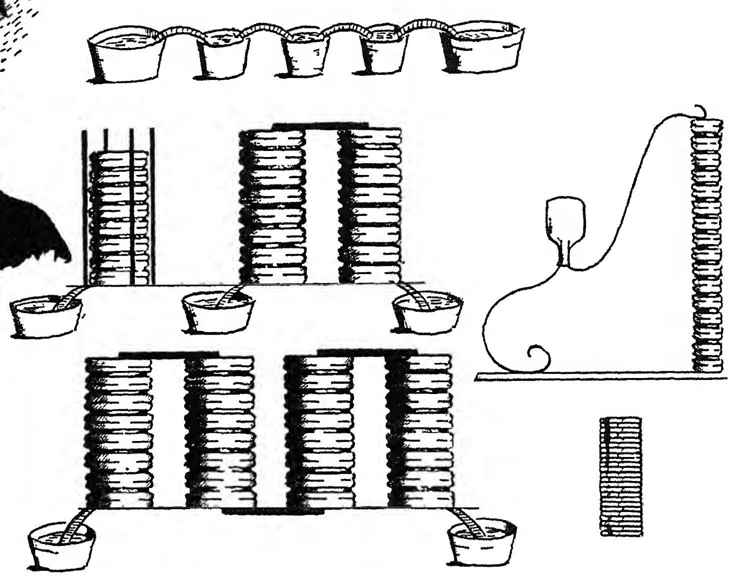
Sir Joseph Banks showed Volta's letter on "the crown of cups" to one William Nicholson (1753–1815), a London civil engineer who had undertaken the publication of a scientific periodical, called NICHOLSON'S JOURNAL. Within a month Nicholson and Sir Anthony Carlisle had constructed their own Voltaic pile. They now found that if two wires connected to the ends of the pile were dipped into water, the water could be decomposed into oxygen and hydrogen through the action of the electric current. This process is called electrolysis, or breaking up by means of electricity; it has proved to be immensely useful in chemical research and in industry.

The invention of the Voltaic pile, or electric battery, represented a great scientific advance. Yet it must be pointed out that the production of electric current by chemical processes — as in the Voltaic pile and the improved storage battery of later times — is comparatively expensive. Before electricity could become widely useful to mankind, a way had to be found to produce large quantities of electricity cheaply. That became possible only when electromagnetism was revealed to mankind. We shall tell the story of this momentous event in a later chapter.

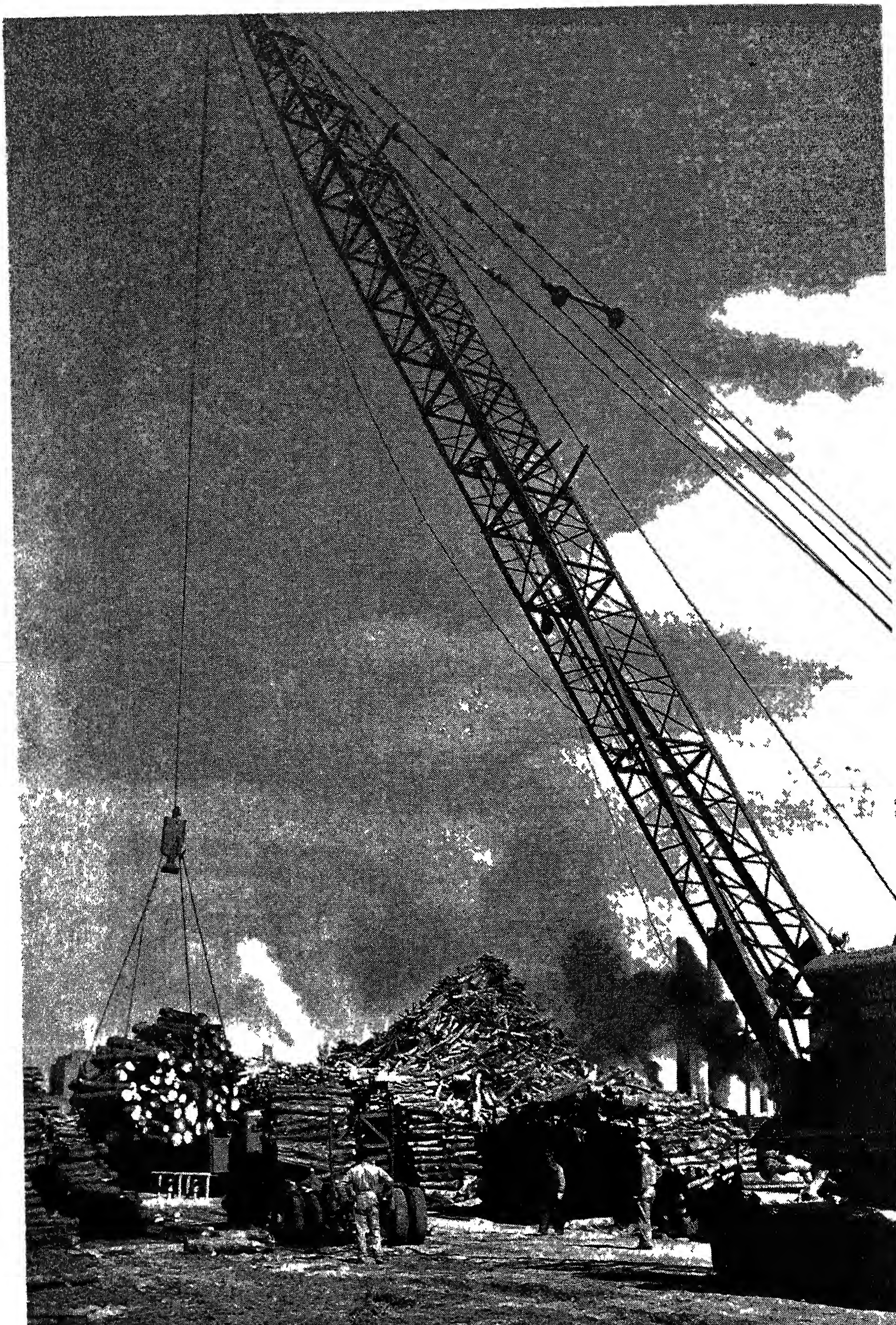
SCIENCE THROUGH THE AGES is continued on page 1658.



ALESSANDRO VOLTA



The drawings show some of Volta's apparatus. Above is his crown of cups, described in his letter to Sir Joseph Banks The other drawings show some forms of the apparatus called a Voltaic pile.



Standard Oil Co. (N. J.)

The big mobile derrick that is shown above is unloading pulpwood from a truck in a paper mill yard

THE KEEPER OF KNOWLEDGE

The Story of the Paper Which Preserves the Store of Human Knowledge, and Makes the Thoughts of Men Immortal

AN INDUSTRY THAT PRESERVES LEARNING

FEW industries are so compacted of hidden romance and fascination as that whose product is one of the most ordinary of commonplace articles — a sheet of paper. Those of us who have grown up in an age of machine-made paper cannot readily imagine a time in which it was scarce and dear, the luxury of the few. Still less can we picture the dark days of an earlier epoch in which it did not exist.

Without water, which is the paramount gift of nature, every living thing would perish; without paper — which is an artificial creation, the work of man's hands — civilization would perish intellectually. Without paper the art of printing would have been valueless and the diffusion of knowledge rendered extremely laborious. Even with the hide of every available animal converted into parchment no substitute for paper would be obtained.

All the learning of the world is committed to paper. The secrets of health, of commerce, of invention and industry, all the music of the dead immortals, all the philosophy and eloquence and varied poetic glories of ancient and modern seer and singer — all is bequeathed to us on paper. Newton had to pause in his mighty task of establishing the mechanics of the solar system until there came to his hand a paper giving him a measurement of the earth's magnitude; the world had to wait for the steam locomotive until George Stephenson learned to read, so that he might master the secrets whose explanation was to be won only from the records of science printed on paper. But for paper, Shakespeare and Milton and Dante would have come down to us in mutilated versions preserved by a few illuminated manuscripts, or by word of mouth from minstrel and stroller. Galileo would have suffered in vain; Harvey's discovery would have been made to be repeated again and again; science and learning and travel would each have been confined within narrow boundaries, the knowledge of each restricted to a narrow circle of men. Paper grew in time to be almost as essential to the advancement of man as oral speech. We do not know when men first began to communicate by written signs. Certainly the idea of blazing a trail in the trackless wilds did not originate with the pioneers of modern days.

Although there have been preserved to us many specimens of the cave man's art, wrought upon rock and flint and bone with the primitive implements ready to his hand, yet we cannot judge what signs he would employ, scrawled upon soft ground or upon the trunks of trees, or upon rocks along the path in the wilderness for the guidance of his followers. Five great systems of writing have been independently evolved, each made up of symbols representing either things or abstract ideas. The earliest was the Egyptian picture-writing. Upon that was based the first of alphabets, the Phœnician; from that sprang two hundred variants, of which fifty are still in use in the world today. These languages were inscribed, with various engraving tools, upon stone, upon clay, upon metal. The oldest known code of laws, the Code of Hammurabi, who reigned twenty-two centuries before Christ, is inscribed upon a block of black diorite.

The tax-collector with his great load of receipts on a donkey's back

From inscription upon stone the next step was the adoption of clay as a medium, the clay, inscribed when in a plastic condition, being afterwards baked or sun-dried to render the record durable. Clay tablets relating to business transactions of all sorts are in existence which carry us back to the twenty-fourth century before the Christian era We cannot but wonder how the tax-collector completed his rounds. He had to give receipts, but these consisted, not of slips of paper, but of a donkey-load of broken pottery, called "potsherds", one of which he had to tender, with an acknowledgment scratched upon it, in exchange for each legal tribute received.

But the astounding civilization of the ancient East, which can be traced back for over seventy centuries, recognized that a better way of writing was to be found than inscriptions upon stone and metal, though these materials had to be retained for laws and treaties and declarations of abiding importance. The ancients discovered the first and only predecessor of paper: papyrus, from which paper takes its name.

How the first sheet of writing paper came into the world

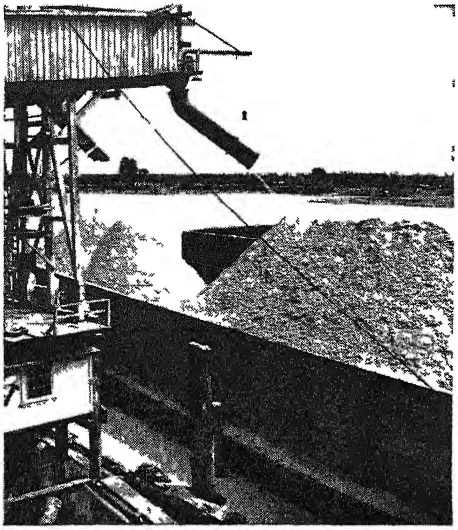
Egyptian papyrus is a kind of sedge, three to ten feet high, growing in the waters of the Nile, in whose upper reaches it may still be seen. It is extinct in Lower Egypt. It had many uses among the ancient Egyptians, its stalks being woven into baskets, even into boats, sails and awnings, and its pith eaten boiled by the poor. There was inspiration in its use as writing material. It marked an advance in inventive ingenuity as great as was the formation of the alphabet upon the picture-writing of the Egyptians. The Egyptians had no model; they began independently with their papyrus, cut the stem into thin strips, placed these together longitudinally with pieces laid at right angles, beat them, and soaked them. The natural gum of the plant caused the strips to adhere, and after these were pressed and dried a sheet of writing material was ready for use.

This material was in use more than thirty centuries before the Christian Era. An early work written on papyrus was the Prisse Papyrus, discovered in a Theban tomb of the eleventh dynasty. This document purports to be a copy of a treatise relating to the fifth dynasty, that reigned about 2500 B C. Systematic search by explorers for the Greek papyri of Egypt has brought to light many official documents relating to laws, taxes and contracts, as well as private letters and accounts.

Papyrus became the medium for the penmen of old Egypt, the pen itself being a reed, and the ink made from some animal carbon, and colored black and red. Although known to early Greek writers, papyrus did not become generally used among the Greeks until after the time of Alexander, when it was extensively exported under the Ptolemies.

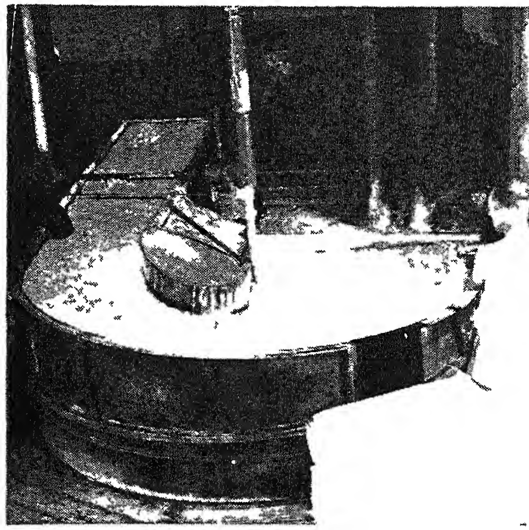
The Chinese labor from which the paper mills of the Western world have sprung

Alexander, then, gave the papyrus to Europe. In the course of his career of conquest he overthrew the ancient city of Maracanda, later to rise anew as Samarkand, which, ever since its capture by the Arabs in 712, has been a sacred city to Moslems. Now, while Alexander was sighing for new worlds to conquer, there was a teeming civilization in China of which he knew nothing. The Chinese had progressed beyond the comparatively rough-and-ready methods of the writers upon papyrus. They had from remote antiquity been making paper, true paper, of silk waste. We make silk today from a paper base, inverting the old Chinese process. When, in the eighth century, the Arabs had become the great scholars of the world, the physicians, the poets, the scientists, they became involved in war with a Chinese army, and their chief joy was that they captured a number of Chinese artisans skilled in the making of paper from fiber. Chinese labor provided the first paper factory ever seen beyond the confines of the Celestial Empire, and from that small establishment set up in Samarkand twelve centuries ago have sprung all the paper mills of the Western world.



Loading woodchips for paper pulp in barges In lumbering, a good deal of the tree is waste material Some of this waste can be salvaged by converting it into chips for paper pulp

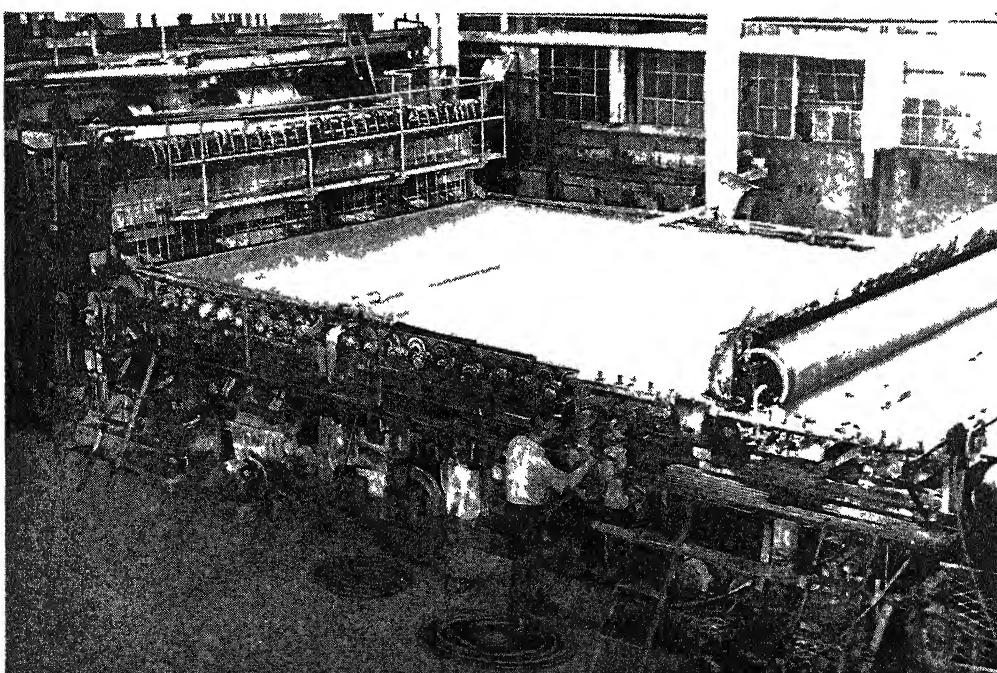
Standard Oil Co (N J)



Lower photos, Champion Paper and Fibre Co

Before the pulp can be made into paper, it must be separated into its tiny, individual fibers For that purpose it goes to beaters, like the one shown here The revolving beater wheel separates and beats the fibers

Highly diluted with pure, fresh water, the pulp flows onto the moving wire of the Fourdrinier machine shown below Before it has traveled five feet, this thin dilution has become real paper.



The industry spread from city to city, to Bagdad, to Damascus, to Egypt, and to cities on the north coast of Africa. The manufacture of paper in Europe was first established by the Moors in Spain in the middle of the twelfth century, centering in Xativa, Valencia and Toledo.

Although the wise men of China could undoubtedly make paper of vegetable fibers, the material commonly used was rags. With the decline of Arab power, the industries which they had established declined in the lands over which they had held sway, and it remained for Europeans slowly to revive and develop the industry which had come in the train of invasion.

The spreading of the art of paper-making to Italy and eventually to England

After Spain, Italy took up the paper-making art, and about 1150 the little town of Fabriano began an industry which it has carried on continuously down to the present day. England acquired its first paper-making enterprise of size through John Spielman, a native of Germany, who settled in England and erected his mill in Dartford in 1568. He employed, we are told, as many as six hundred workmen, in a plant that was visited by thousands of curious sightseers.

Among the Huguenots who left France for America when Louis XIV in 1685 revoked the religious freedom edict were many skilled paper-makers. They were not long idle in the New World, for in 1690 the town of Roxborough, near Philadelphia, boasted the first paper mill in America. It was built and operated by William Rittenhouse. Forty years later a company in New England obtained the exclusive right to manufacture paper in the Province of Massachusetts for ten years. A similar right had been granted to Spielman in England in 1589, in a license which read: "for the gathering of all manner of linnen raggs, scrolls, or scraps of p'chment, pease of lymes, and clippings of cards, and oulder fishinge nettes, for the making of all or anie sort or sorts of white wrighting paper, and forbidding all other p'sons for the making of paper, for the space of ten years next."

The first machine for making paper did not make the inventor's fortune

The terms of Spielman's license indicate the nature of the materials upon which he relied for the making of his paper. His wares, like those of all other makers down to the close ot the eighteenth century, were entirely hand-made, produced sheet by sheet. The rags employed were beaten into fibers by rough-and-ready mechanical appliances which were worked first by hand, and afterwards by wind and water power. The process was so slow that the output was necessarily restricted, with the result that the store of raw material available quite sufficed to meet all demands. But, intricate as is the work of the paper-maker, it has not proved too complex for machinery.

In 1798 Louis Robert, a workman in a French mill, took out a patent on a machine which made paper in an endless web. Like many others who have conceived the idea of a great project, Robert did not receive the credit for a practical application of his ideas. It remained for another to contribute not only his skill, but in this case his fortune, before the machine was finally perfected. Henry Fourdrinier was an Englishman, and a son of one of the old school of hand paper-makers. He, with his brother Sealy, spent and lost $300,000 in developing the machine which first opened the way to the unlimited supplies of paper which the manufacturer can now command. These men may well be considered the founders of modern paper-making, for so complete was their work that the early machines differ but little from the most modern ones of today.

The need for finding a new material from which paper could be made

Fourdrinier's first patent was taken out in 1801, and with his machine the industry received an impetus which has led to the development of the additional apparatus and equipment of the modern paper mill.

With the tremendous growth of the new industry came a shortage of the original raw material — rags. The demand for paper assumed enormous proportions.

Newer transportation methods facilitated the distribution of the mail, and, as a result, correspondence rapidly increased and newspapers multiplied. Supplied with a machine and his market, the manufacturer was compelled to cast round for an entirely new source of supply of raw material. He had to find a vegetable substance which he could resolve into its constituent fibers to replace the ready-made fiber of the rags of linen and cotton, etc., which he had been in the habit of using.

The wasp that has held the paper-maker's secret for ages and ages

Probably he did not go to the wasp for guidance, but it was there that the secret lay. The wasp has been from the beginning of insect history masticating woody and other vegetable fibers and producing paper from them. And that is what the modern paper-making plant does. It is a colossal mechanical wasp, which masticates wood and grasses and the straws of cereals, and binds their fiber into miles upon miles of paper.

Esparto, or alfa grass, was the first vegetable substance with which commercial success was gained, and an extensive trade sprang up in paper made from this substance, and southern Spain and parts of northern Africa were exploited for the grass which had suddenly become an asset. But soon demand outgrew supply, as in the case of rags. Where the rag-gatherer had formerly kept the paper market going, now, with the spread of education, rags, plus enormous supplies of esparto, failed to satisfy the needs of the paper mills. Rag returns about half its weight in paper; esparto yields about one-sixth of its weight. So other supplies had to be found.

The search all the world over for materials that will make paper

The world has been ransacked for suitable vegetable growths. In scores of mill offices one may see little bundles of dried vegetable fiber, numbered and described. The traveler in the distant wilds sends these home, with a memorandum saying: "The natives call this substance so-and-so; they use it for such and such a purpose." The manufacturer consults the botanist and the chemist for an answer to the question: Will it make string or rope, or sacking or canvas? Best of all, will it make paper? Experiments are constantly in progress in chemical laboratories throughout America and Europe with a view to discovering new supplies from the growths sent from afar. Edison sent men on a world-wide tour to gather materials out of which to fashion filaments for his incandescent lamp, but the paper-maker has men constantly out and about the world.

He gathers flax from Russia, Turkey, Italy. Egypt, France, Belgium, and Ireland. He takes the hemp of Russia, Italy, Turkey and Hungary and New Zealand, and the best that India can grow. He uses cotton from our Southern States, Egypt, and India; jute from India; straw from Holland, Germany, and our own country; esparto from Spain, Algeria, Tunis — and Tripoli. These are the principal sources of fixed supply. But they do not suffice. The chemist has to be summoned to analyze unconsidered potentialities. And in the end he reports favorably on the straw of flax, on banana skins, bamboo, the dried stalk of the sugar-cane, on peat, on the waste hulls of cotton seed. The paper-maker goes back to nature for inspiration. In her laboratory there is no such thing as waste, and he finds in waste products raw material for his trade, yielding greater treasure even than is hidden in all the tons of refuse containing radium, which were scattered on the dump-heaps of every great city in days when radium was unknown.

The basis of a library which is formed in a forest

But, so far, we have said nothing of the pulp of wood. That, today is the great stand-by of the paper-maker. The giant of the forest, subdued by machinery, becomes a pulpy mass which the great mechanical wasp bleaches and beats and hardens and smooths and glazes until it issues from the machine in the form of paper, indistinguishable by any but an expert from paper that is made from cotton and linen rags.

At first sight it might perhaps appear that, with the forests of the world from which to cut, the paper-maker would have sure supplies for all time. That, however, is far from the fact. Only certain trees are of service for paper, and resources have to be carefully husbanded. For a number of years the destruction of trees for pulp, among other purposes, has been so serious that the world has been brought within sight of a paper famine. So now the paper manufacturer, who was already an expert chemist and mechanical inventor, has turned forester. Instead of stripping forest land bare of trees, he cultivates his forest. He cuts down trees, but he plants others, so that while he is thinning out his thousands of acres of tree-covered land, new growths are springing up in his footsteps. The paper forest of today, in the hands of the scientific paper-maker, is as carefully conserved as the rubber plantations called into being by man.

Having now examined the sources of the paper-maker's raw material, we may glance briefly, without penetrating into technical details, at the processes which convert that raw material into the finished article.

The raw material in its early stages at the paper mill

We have three groups of substances — rags, wood-pulp, and grasses and other fibers. The rags, upon arriving at the mill, are freed from dirt, from buttons and all hard substances, and, to obtain the best results, cut by hand into strips about four inches square. However, as this is a costly method, the cutting is generally done by machinery. The rags are sorted into various grades, next beaten and whirled in a revolving "duster," then boiled under pressure in revolving cylinders in a chemical solution which removes all coloring matter and renders the fibers flexible. The solvent used is, as a rule, caustic soda, which, by an ingenious process, is afterwards recovered from the water. Considerable care is required with the rags in this stage, as the strength of the alkaline solution in which they are immersed needs frequent modification.

The initial cleansing of the rags leads to the bleaching. This may be carried out by placing the rags for from eighteen to twenty-four hours in tanks of bleaching solution. But there are other methods, and this one is slow and rather costly.

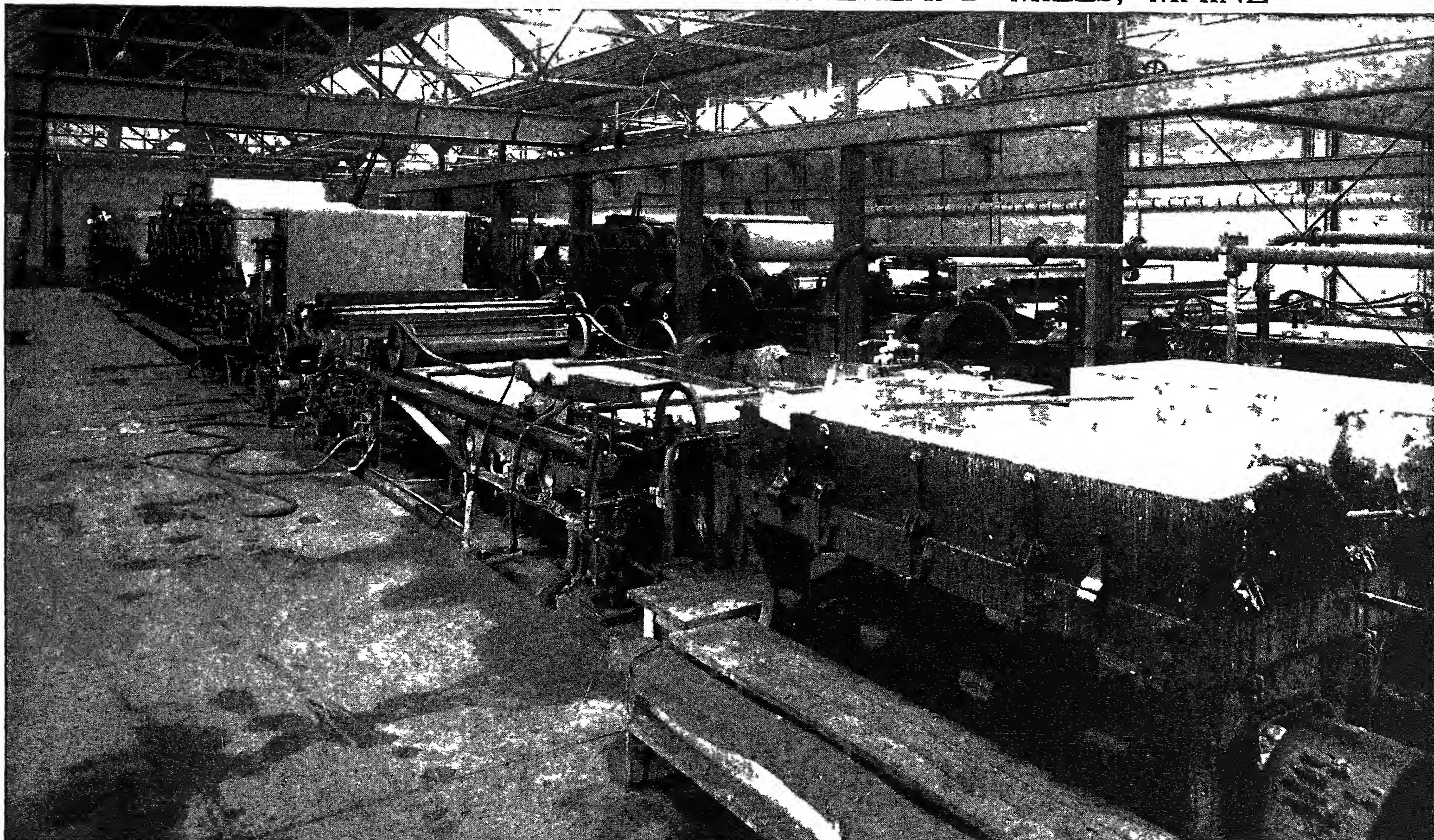
The process by which rags and grass are beaten and made into paper

All materials for paper-making need bleaching, and a modern installation includes a considerable bleaching plant — a series of towers, to each of which the substance passes in turn by mechanical action, to be compressed, bleached, washed, beaten into fibers, and turned out, ready for the machine, in quantities sufficient to yield sixty tons of paper a week. For present purposes we assume them to have been washed and bleached by the first process.

Following this preparation they are removed to a vessel called the "breaker." This is a vat, whose mechanism includes an iron roller fitted with knives, which pulp the rags into fibers. In this breaker the rags are caused to circulate for some hours. Clean water is from time to time introduced and the foul liquid withdrawn, so that the last vestiges of dirt disappear with the soda in which the first process had been accomplished. If bleaching is to be carried out in the breaker, the powder is introduced at this stage, and the "stuff," as it is now called, passes to the refiner, a modern machine in which a further clarifying is effected. Thence it is forced through pipes to the paper-making machine proper.

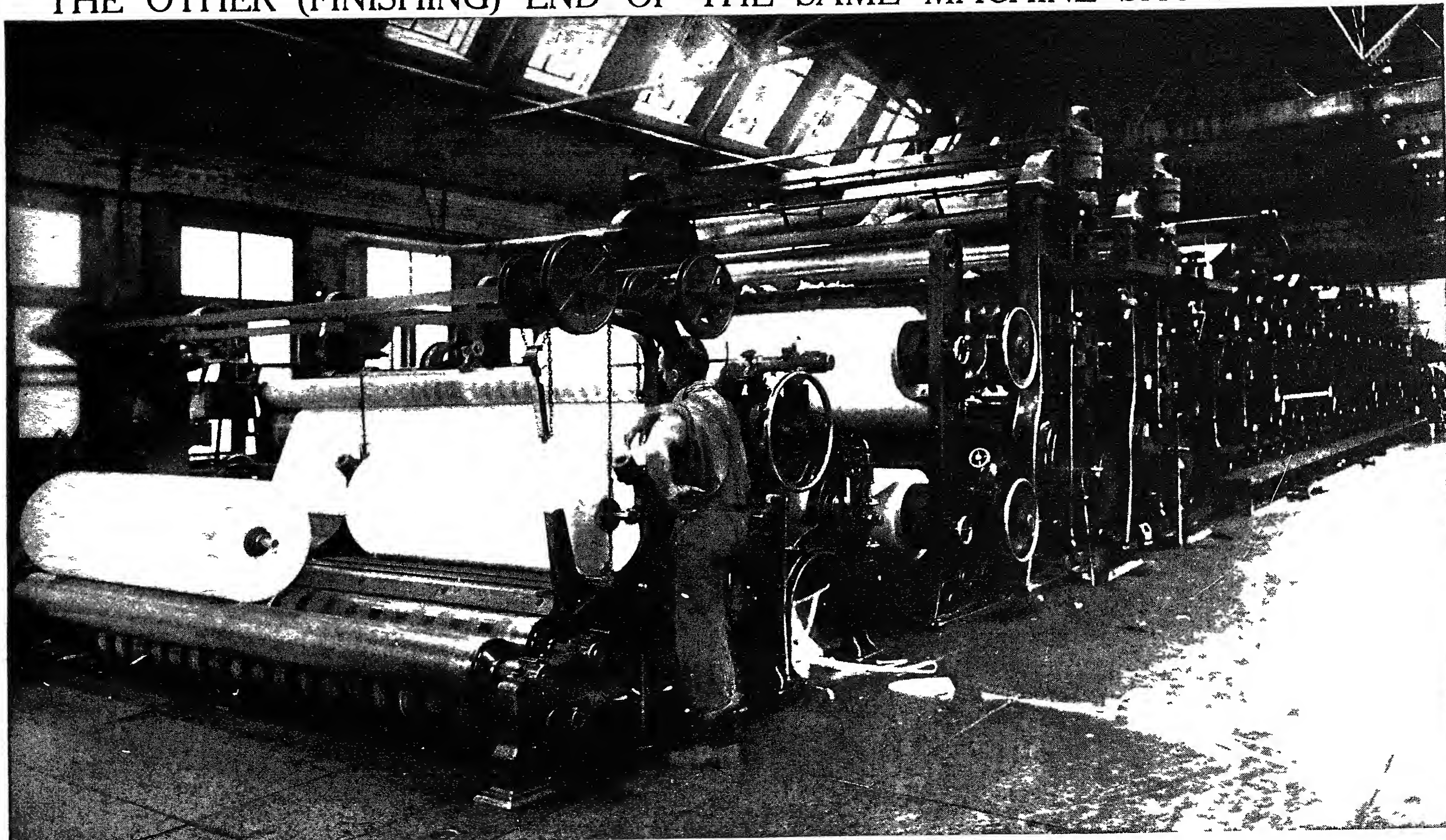
The treatment of esparto grass differs in its first stages from that to which rags are submitted. The end to be achieved is to resolve the grass into its fibers, free from all intercellular matter. It is placed in a peculiar type of boiler, where it rests upon a perforated false bottom. Through this the boiling liquor drains, to rise at the sides and be pumped as a spray upon the grass. By this means a constant circulation of moisture is maintained. The grass passes to the "potcher," which is similar in action to the "breaker," and is broken into fibers of approximately even length. It is afterwards bleached and refined.

FOURDRINIER MACHINES IN CUMBERLAND MILLS, MAINE



Paper-making machines are run twenty-four hours daily, from midnight on Sunday to midnight the following Saturday. In the foreground is the so-called "wet end" showing the vats in which the liquid pulp, about 98% water, is pumped It is screened and then flows on to an endless wire web beyond, where the free water is taken out by drainage and by suction boxes

THE OTHER (FINISHING) END OF THE SAME MACHINE SHOWN ABOVE



FOURDRINIER MACHINES IN CUMBERLAND MILLS, MAINE

As the paper progresses through the machines it passes over a long series of heated cylinders, drying and hardening the stock until it reaches the finished end This illustration shows a web 135 inches wide being cut into two rolls The air pressure in the machine room is slightly greater than the atmospheric pressure outside, preventing dust from entering

Two kinds of wood pulp from which paper is made

In America the manufacture of wood pulp has developed to such an extent that many mills exist for that purpose alone. Wood pulp is of two kinds — mechanical and chemical. Mechanical pulp, which is for the cheapest papers, consists simply of the trunks of trees ground to pulp, and containing all the substances of the original wood — the resin, gums, encrusting and intercellular matter. Chemical pulp consists of the fiber of the wood from which all foreign substances have been removed by chemical action. The first yields a cheaper but weaker paper than the second, and of course is not so enduring a fabric. Spruce, fir, poplar, and hemlock are the trees to which the manufacturer principally has recourse. The trunks are cut into short logs, stripped of bark and knots, ground by machinery to chips, and then treated, either by a cheap and expeditious method, or by the more costly chemical process. After the mechanical pulp has been ground and boiled and beaten and bleached it comes out in thick strips resembling the "stuff" of cheap cardboard. The chemical is a more presentable product, to the paper-maker's eye, though the difference in texture might not be specially obvious to the uninitiated observer.

Arrived at the mill, the pulp begins its career of transformation in the breaker. Here it is churned and beaten until it presents the appearance of an enormous caldron of thick porridge. While it is in this stage, dye is added, if the paper is to be colored. It follows the course of the rag-pulp — to the refiner, and, like that substance, is now ready for the machine, to which it is forced through a heavy pipe.

The machine in which a running stream becomes a roll of paper

Properly mixed, the stuff leaves the breaker composed of five per cent of fiber and ninety-five per cent of water. It is to the eye at this stage merely a cloudy fluid; it leaves the machine at the opposite end as part of a roll of paper five miles in length, wound upon a huge reel!

The machine by which the seeming miracle is wrought is one of the largest and most complex of all machines. That shown in our illustration is more than two hundred feet long. It works day and night, automatically feeding itself with pulp, and converting it into paper 142 inches wide, at the rate of 500 feet a minute, twenty-four hours a day, with only a skilled man or two in watchful attendance.

The first time that the material is actually touched by hands after being thrown into the beaters is when men take it away on running pulleys in the form of completed rolls of paper, ready to be cut into narrower widths for the use of the insatiable printing presses of the world.

The moving table of wire which carries a stream of flowing paper

One or two outstanding features of the progress from fluid to solid paper may be noted. Between the breaker and the machine comes the refiner, and a stuff-chest is also provided, serving, in the modern machine, only as a reserve supply in order that the machine may not be kept waiting should the refiner go amiss. From this point the stuff is forced to a mixing chest, where the proportions are modified to from one-half to one per cent fiber and the rest water.

Should the refiners fail, the stuff-chests are the starting point of the mixture, but normally this comes direct from the refiners. In these the final purification has been undergone, though a straining process follows for the elimination of lumpy matter. Hence the stuff passes to what is called the "breast-box" of the machine, from which it overflows on to a wide stretch of endless wire netting of very fine mesh, upon which it is carried at rates varying from 40 feet to 500 feet per minute, according to requirements. This moving table of wire cloth is cunningly contrived to impart a rocking motion, in imitation of the shake given manually in hand-made paper. But the force is graduated so that while the wire cloth is rather violently oscillated at the point nearest the wet end of the machine, the vibration dies away in the mechanism nearest the dry end.

The purpose of the oscillations is to prevent clogging by keeping the pulp in motion. A large quantity of water passes from the stuff through the meshes of the wire cloth, at the end of which what may be described as "fluid paper" appears. The stream along the wire cloth thickens and becomes more and more opaque. It passes now over a series of suction boxes, each of which in turn extracts a quantity of moisture from the moving stream of coagulating fibers. In the case of paper which is to be water-marked, the operation is performed at this stage, a revolving cylinder bearing a design in wire which is pressed into the very fabric of the soft moist paper. After passing the suction boxes the paper — for such in the rough it has now become — is conducted between a series of rollers covered with thick felt, which squeezes moisture from both faces in turn.

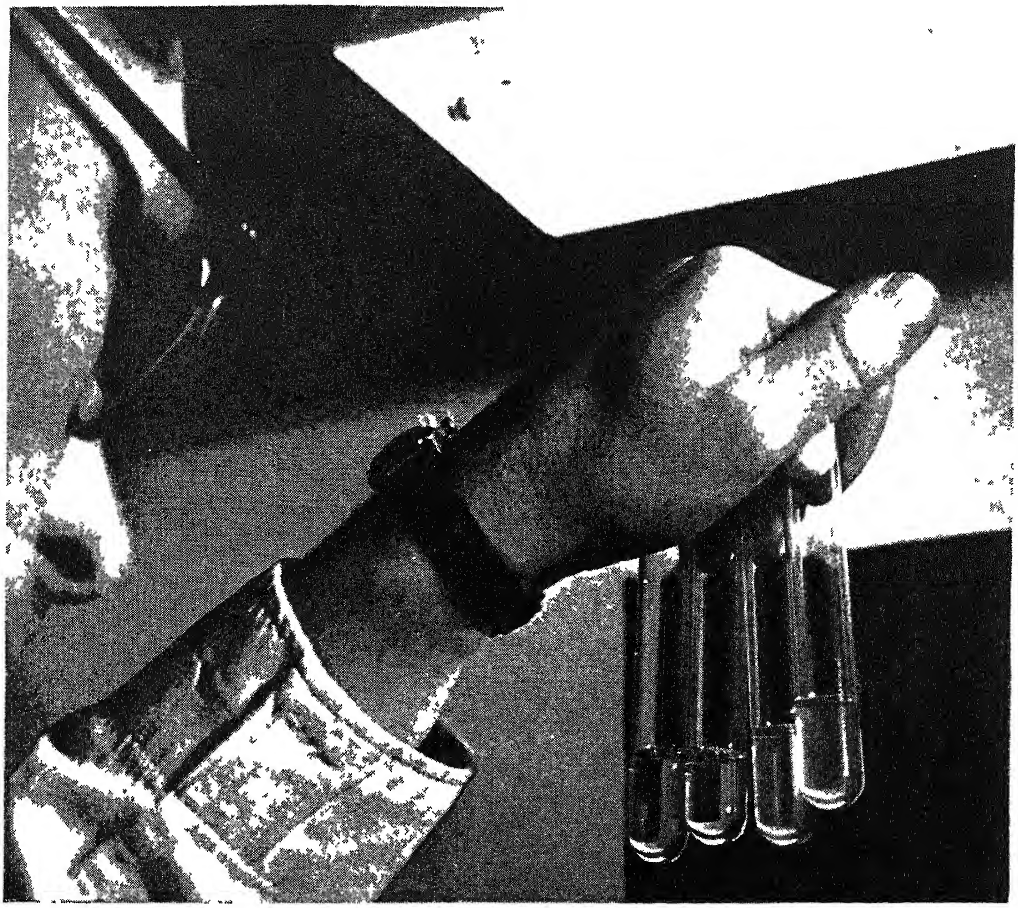
Next the paper is led round a complicated series of revolving cylinders which are heated with steam. These complete the drying process, and there remains only the "calendering," the passing of the paper between successive pairs of cylinders which impart an ink-resisting surface. There is needed then only the cutting of the paper into sizes required by the printer.

In spite of the manifold wonders of the machine, hand-made paper is still the best, just as a hand-sewn shoe is better than the product of the machine. The initial treatment of the rags — of which hand-made paper is exclusively formed — is the same as for machine pulp, up to the point at which the breaking and refining are completed. There the worker takes the fibers in hand, and, in place of the endless band of wire cloth, uses a hand frame of similar texture, which he can jerk and twist in such a manner as to make the fibers felt more satisfactorily than is possible by the automatic oscillations performed by the machine. While the pulp is on the wire cloth, the water-mark is impressed by a pattern in the wire slightly raised above the level of the rest of the surface. The pulp is transferred, after the necessary shaking and draining, to a sheet of felt, and with other sheets is pressed and dried, sized and calendered, ready for use.

It will be noticed that in surveying the machine at work we have taken account of only the cheaper form of paper, such as is used for newspapers. For papers requiring more "body" and a better surface, china clay and other substances are introduced into the stuff, and the paper undergoes a more extended calendering to give firmness combined with gloss.

But, enormous as are the demands upon the paper-maker for newspaper purposes. the industry embraces many makes of paper which never come in contact with a printing machine. The uses of paper are almost limitless. It can be made into a remarkably good imitation silk, into yarn, into sacking of an excellent type, into impermeable "canvas," into a perfect and most compact insulator for electric wires. It plays an important part in making commercially possible the laying underground of the telegraph wires of the country. Cheaper than gutta-percha, it is so thin that a great number of wires can be perfectly insulated by paper in a very small space. How strong the thinnest of papers can be made is shown by the remarkable tenacity of the banknote. We also have dinner services of paper; safety matches of paper; wrapping papers, paper bags, transparent glassine and wax paper. Paper is also used for building purposes: among the "building papers" are wallboard and roofing felt.

These startling applications of the paper-maker's art are of modern development, and the possibilities open to him seem to be innumerable. He has an unlimited market, but he has not an inexhaustible supply of raw material upon which to draw. A fire may ruin his forest, a drought may bring his mills to a standstill, imprudence may unduly impoverish his resources. The threat of a famine in pulp has made the paper-maker jealously treasure the forests upon which he has to depend. He cuts down, but he plants again. He thins out his forest and plants new trees in the place of old, so that "once a forest always a forest" has become his ideal in respect of the land whence his pulp is drawn. There has long been a cry for scientific forestry, and the exigencies of the paper trade have brought it into being.



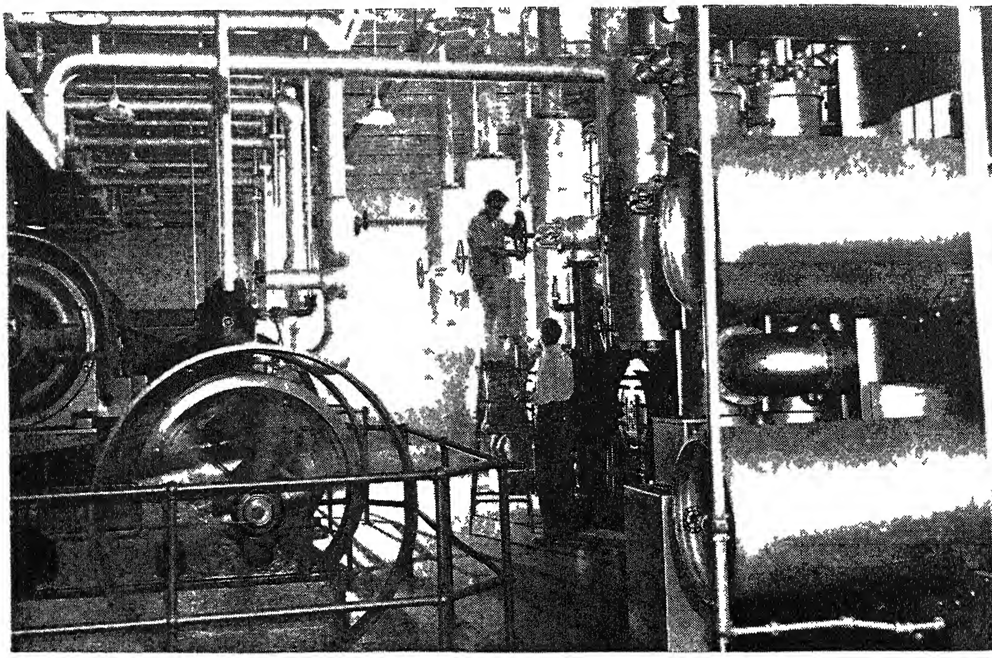
British Information Services

Tubes of clear diluted penicillin, to which bacteria called staphylococci have been added, are kept overnight at human body heat. If the penicillin is strong enough to kill the staphylococci, the tubes will remain clear. If the tubes become cloudy, more penicillin will be required in the solution.

PENICILLIN AND STREPTOMYCIN

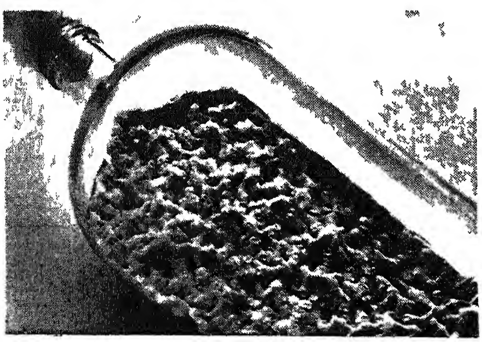
Two of the most effective germ-killers that have been developed in recent years are penicillin and streptomycin. Penicillin is an acid produced by the mold *Penicillium notatum.* The acid was discovered by Sir Alexander Fleming in 1928, but it was not put to practical use until some ten years later. The mold is grown in vats or flasks in a liquid; the liquid is then treated chemically and evaporated. Penicillin is effective in treating acute infection of the blood, heart, eyes, ears and bones; it also serves to prevent infection in open wounds.

Streptomycin is sometimes successful in fighting diseases that resist penicillin. It is an extract of a bacterium that grows in the soil — *Streptomyces griseus.* Streptomycin was discovered in 1939 by a team of scientists at Rutgers University, headed by Dr. Selman A. Waksman. Streptomycin is invaluable in the treatment of pneumonia, typhoid fever, dysentery, undulant fever and gas gangrene.



Chas Pfizer and Co

Air compressor supplying air required in the fermentation step In this, the solution in which the mold has been grown undergoes a series of chemical changes The preparation of penicillin is now on a mass-production basis, machinery has taken the place of laboratory technicians in many operations.

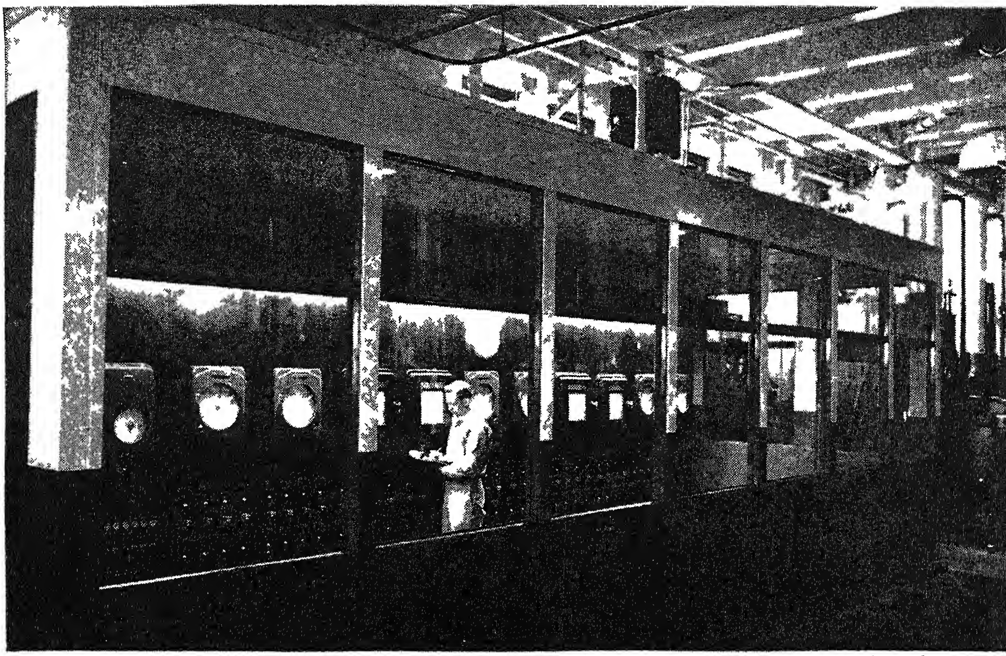


The mold *Penicillium notatum* growing in a flask. Today molds are grown mostly in huge vats.

How the mold looks in its natural state. The drops of clear liquid on the surface of the mold contain a good deal of the germ-killing penicillin

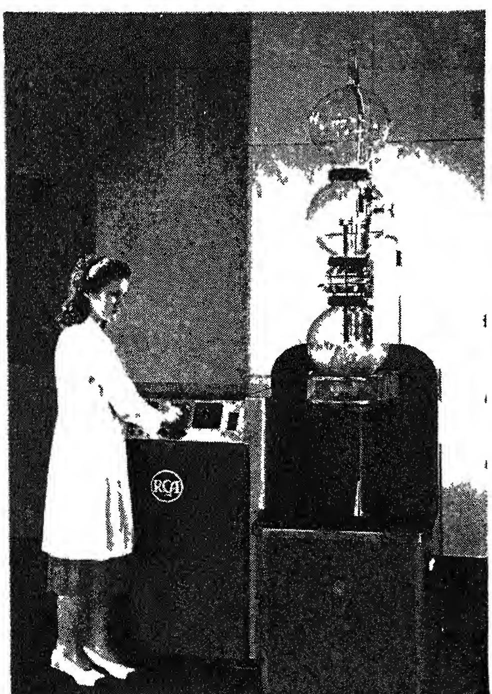
Three lower photos, E R Squibb and Sons

Penicillin is obtained by decanting (pouring off gently) the liquid matter contained in the flask or vat. The solid mold matter is then discarded.



Chas Pfizer and Co

This control panel is used in the extraction and purification processes in the preparation of penicillin The liquid in which the mold has been grown is drawn off and undergoes a long series of refining processes Each step must be very carefully controlled in order to obtain a uniform product.

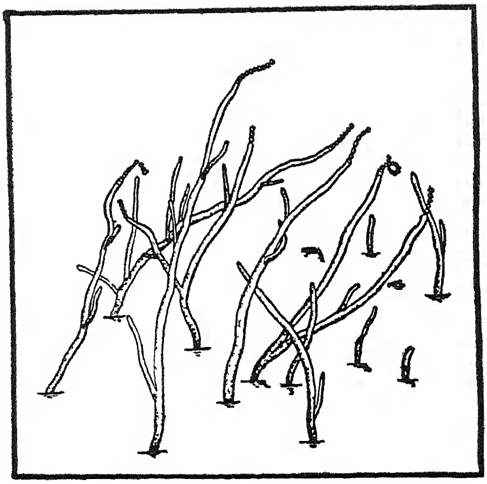


RCA

An all-electronic penicillin bulk-reducer, which concentrates the penicillin solution The machine turns out 2,000 vials of penicillin every hour.

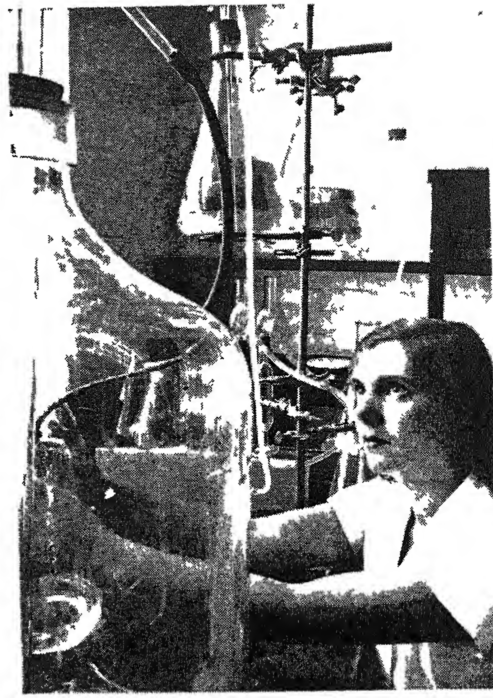
Chas Pfizer and Co

These operators are sealing, labeling, inspecting and packaging the vials of penicillin The wonderful drug is now ready for medical purposes.

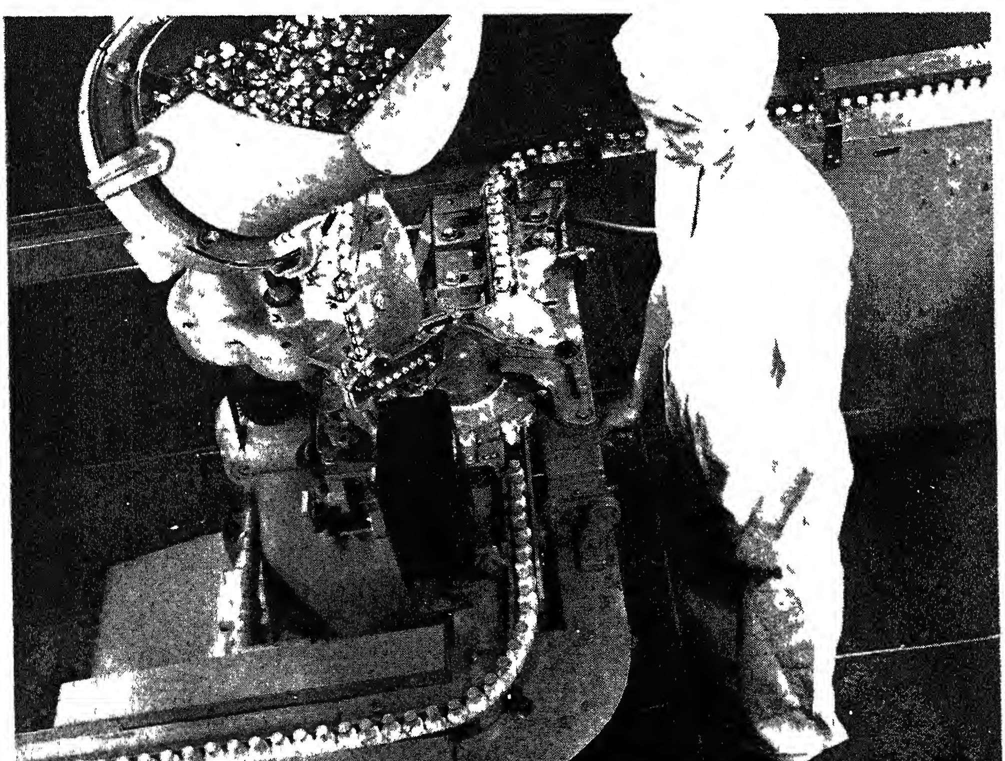


Drawing and upper photo, Chas. Pfizer and Co.

The grass-like growths in this drawing represent a microscopic view of *Streptomyces griseus*, the organism from which streptomycin is derived.



Right: a technician is preparing solutions that are to be used in testing freshly prepared streptomycin. The tests are given in order to find out how potent and stable the streptomycin is.



Merck and Co, Inc.

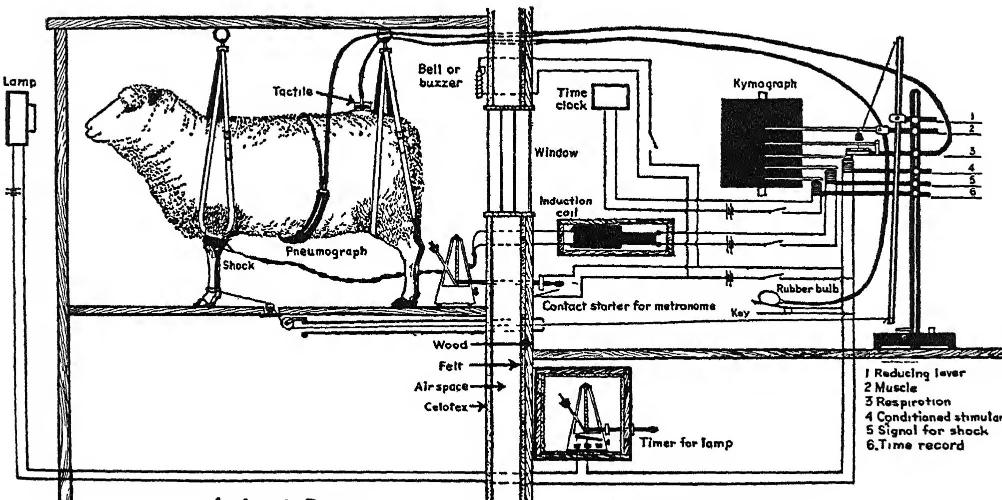
The final stage in the preparation of streptomycin. The machine in the picture is crimping on aluminum seals over the rubber stoppers of the vials, thus providing double protection for their contents.

REFLEX ACTION AND INTELLIGENCE

Instinctive Behavior and Voluntary Action

IT is not easy to furnish an accurate description or a satisfactory explanation of animal behavior, especially when the actions that are to be described are supposed to indicate intelligence. The brain is the seat or organ of the intelligence. In order to understand how the brain of an animal works, we must focus our attention on intelligent or voluntary action. Here we meet a curious obstacle. It is almost impossible to give an accurate description of the actions of a familiar animal, such as a dog, without calling upon our imagination. For example, we say, when we see a dog wag its tail, that it is pleased. This is really an interpretation of what we see, rather than a straightforward, factual account. We believe we have an insight into the reasons for our own actions. We come to believe that we can as easily interpret the conduct of other humans or of animals.

Until the beginning of the present century, the usual methods of physiology were thought to be inapplicable to the study of the brain as the agent of intelligent action. This study was held to be the special province of psychology, because the sensations we experience depend upon the brain, and the only way in which we can know of sensations is to observe them in ourselves, or to learn about them from others. Animals cannot tell us about their mental lives. Therefore, we are unable to interpret their behavior except through its resemblance to our own. From this point of view the position of physiology is paradoxical. Its methods are adequate for the study of all the parts of the nervous system except the

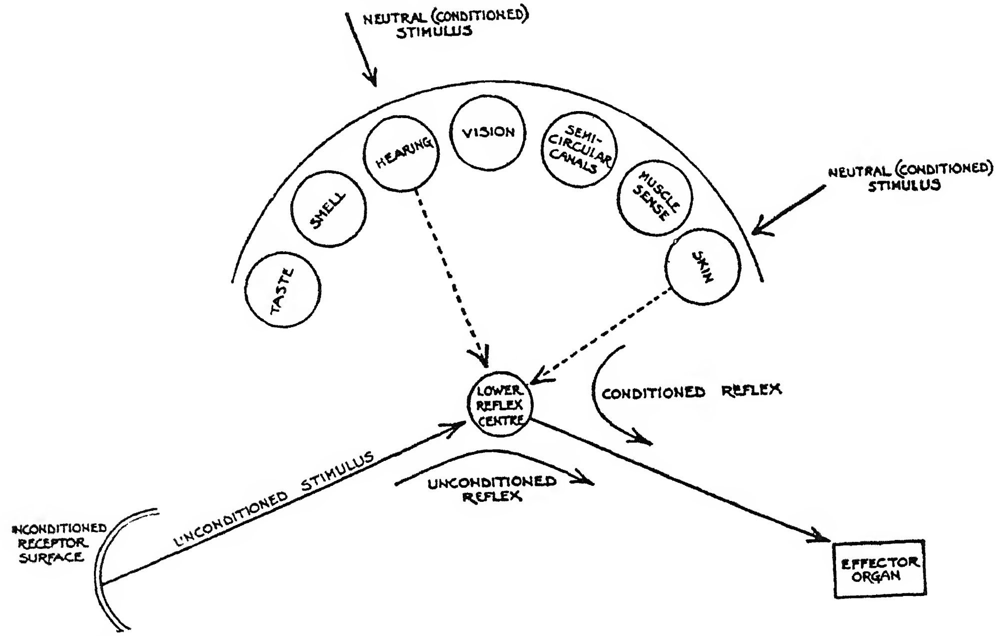


Drawing by B R Macmillan

Fig. 1. How the Russian physiologist Pavlov studied conditioned reflexes. When electric current was sent through the wires attached to the sheep's leg, it pulled up its leg. A cord attached to the animal's leg and running to a lever in an adjoining room recorded the action on moving smoked paper.

brain, but it is necessary, according to this view, to study the activity of the brain by the characteristic method of psychology, viz. introspection or self-observation. There is no reasonable doubt that through introspection we are able to gain information about our behavior that will eventually prove essential in understanding the action of the brain Recent research convinces us, however, that equally valuable information can be obtained through the use of the same methods that have been so successfully applied to the study of the lower parts of the nervous system, i.e. nerves and spinal cord.

Most of our knowledge of the functions of the nervous system has been derived from experiments in which the brain is severed from the spinal cord. Death does not necessarily result from such an operation. Even in man the spinal cord has, in certain cases, been accidentally torn across, but the victim, although paralyzed below the region of injury, has been kept alive. After a period of depression certain automatic actions are carried out by the isolated spinal cord and its nerves. For example, if the sole of the foot is pricked with a pin the muscles of the leg will contract to pull the foot away from the injurious stimulus. In a dog without a brain if the skin over the ribs is tickled by a bristle the hind leg will perform scratching movements directed toward the region of irritation just as a normal dog would scratch at a flea. Again, if a dog with severed spinal cord is lifted to its feet the limbs cannot support the body but if the animal is held in the air so that the hind legs hang vertically they will begin to execute walking movements. The above instances illustrate reflex action, the simplest automatic activity of the nervous system.



From C. Lovatt Evans' *Recent Advances in Physiology*

FIG. 2. DIAGRAM TO ILLUSTRATE THE ESTABLISHMENT OF CONDITIONED REFLEXES. TWO ARE SHOWN, ONE FOR HEARING AND ONE FOR SKIN STIMULI

The living mechanism upon which reflex action depends is not complicated. It is called the reflex arc and consists of the structures represented in Figure 2. If the sensory or receptor surface, e.g. the skin represented at the left of the diagram, is stimulated, a wave of chemical change or nervous impulse is aroused in a nerve fiber and travels to a nerve center indicated by the circle at the center of the diagram. From this reflex center a new im-

pulse is transmitted by another fiber to an effector organ at the right of the figure and the activity of this organ (muscle or gland) enables the animal to respond to the stimulation or change in environment to its best advantage. For instance, if the skin of the foot is pricked the leg will be pulled up or flexed. The disturbance caused by the pin prick is conducted to the central nervous system and is then reflected back to the muscles of the leg. Thus the action of the pin evokes the appropriate defensive reaction of muscular movement. An irritating substance introduced into the mouth evokes a copious flow of watery saliva to wash away the injurious substance. In this case the effector organ of the reflex arc is a gland whose appropriate reaction is a secretion but the reflex mechanism is the same as before.

This simple scheme of reflex action to explain automatic or unintelligent behavior must be qualified. The nervous system consists of millions of possible reflex arcs all of which can be placed in connection with one another. If a little strychnine is injected under the skin of a decapitated frog the slightest stimulation of any part of the body surface may produce a spasmodic contraction of all muscles. In this case the stimulus applied to a receptor acts, not on a single reflex center, but on all centers at once. It could not do this unless connections already existed among them. Under ordinary circumstances some of these pathways are more easily traversed than others. This explains why the animal's reactions are orderly or purposive rather than chaotic. Strychnine, by destroying the varying resistances of these nerve tracts, discloses the fact that all nerve centers are potentially connected.

Although the notion of reflex action is generally accepted as the fundamental plan of automatic or instinctive behavior, intelligent or voluntary action depending upon the brain has seemed to require a different explanation. It has been further assumed that the psychologist must provide this explanation. The reason for this assumption has already been mentioned. As a matter of fact the brain consists of the same structural elements found in the lower parts of the nervous system, viz. nerve centers connected by pathways of nerve fibers. Is it, then, possible to apply our scheme of reflex action to the explanation of intelligence?

As contrasted with automatic or involuntary behavior, which exhibits an almost machine-like regularity, intelligent action is characterized by its spontaneity and flexibility. An animal, in order to survive, must be able to modify its behavior when confronted with a new situation. We may define intelligence, then, as the capacity for modifying behavior. Now if an animal such as the dog is deprived of its brain it is no longer capable of profiting by experience and its actions become stereotyped and impulsive. In order to account for modifiable or intelligent behavior in terms of reflex action it is necessary to postulate new and temporary reflex arcs formed in the brain as a consequence of the many novel conditions encountered in a constantly changing environment.

The Russian physiologist, I. P. Pavlov, was the first to attempt to study intelligent behavior as a special case of reflex action. On the basis of many years of experimentation with dogs he classifies reflexes as of two types: unconditioned or inherited, and conditioned or acquired reflexes. According to his theory, conditioned reflexes depend upon reflex arcs formed in the brain under the influence of environmental forces during an animal's life span. They are the unique possession of the particular animal and may be exhibited by no other member of the species. One's individuality is largely determined by his conditioned reflexes for this reason. New reflex arcs originate and persist only under certain conditions which it is the business of the physiologist to discover and control.

This new field of study has, hitherto, been explored only by its discoverer, Professor Pavlov, and his pupils, using the dog as the experimental animal. In the remainder of this chapter we will illustrate the methods employed and the results obtained from the study of conditioned reflexes by instances chosen from recent work done in America on sheep. These

animals, famous for their alleged stupidity, are, nevertheless, almost ideally suited for experiments on intelligence because of their docility and the relative simplicity of their behavior.

The arrangements for a conditioned reflex experiment are shown in Figure 1. The sheep is taught to stand quietly on a table. Wires are fastened to the left foreleg through which a weak electric shock can be applied. When the shock is administered the animal pulls up its leg and a thread running to a lever in the adjoining room records the reaction on a moving smoked paper. This response to the shock is an inherited or unconditioned reflex. It could be obtained just as well from an animal without a brain and depends upon a series of simple reflex arcs already established in the sheep's nervous system at birth.

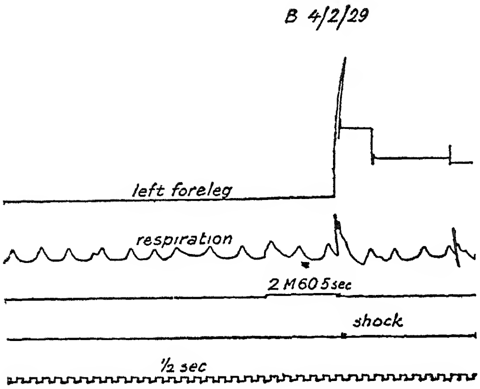


FIG. 3

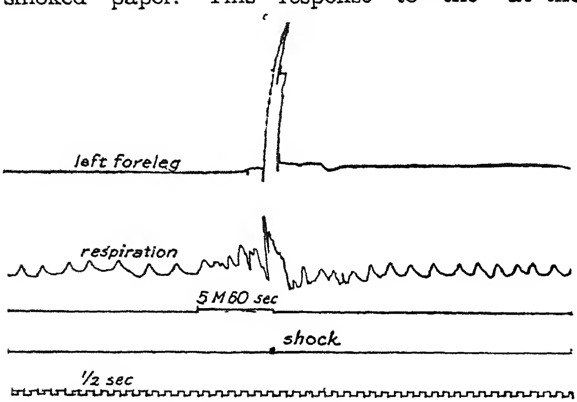


FIG. 4

Now if some sound, such as the beating of a metronome, precedes the electric shock a number of times it will become a signal warning the animal of the approach of the painful stimulus. Finally, when the metronome begins beating the animal will flex the leg as violently as if it were receiving an actual shock. It will be noted that the first indication of the new reflex to sound is given by the disturbed breathing when the metronome is started for the fourth time (Figure 4—$5M_{60}$ on the third line from the top of the tracing means the fifth presentation of the metronome beating at 60 per minute). In each successive test the breathing during the beating of the metronome becomes more disturbed until finally the first anticipatory leg movement occurs when the metronome is sounded and before the shock is felt.

In other words, the sound acting on the receptors of the ear now evokes defensive movements of the foreleg as effectively as the electric current itself. According to the conditioned reflex theory of intelligence, a new reflex arc has been formed in the brain connecting the center for hearing with the lower reflex center for the muscles of the leg. The new nervous pathway is represented in Figure 2 by the dotted line at the left. Any other sensory center of the brain could, of course, be similarly linked by a new connection with the lower reflex centers for unconditioned reflexes.

The development of the auditory conditioned reflex just mentioned is shown in the records (Figures 3 to 6) of an experiment upon a sheep two years of age. These records* are to be read from left to right. Time intervals of one-half second are traced on the bottom line. The top line is written by a stylus attached to a lever connected with the sheep's left foreleg. The second line from the top traces the breathing movements. The sudden rise in the third line indicates the moment at which the metronome behind the animal begins beat-

*From unpublished results of experiments performed by H. S. Liddell, O. D. Anderson and W. T. James of Cornell University.

ing once a second. The fall of the line after a few seconds marks the stopping of the metronome. At this point the upstroke on the fourth line records the electric shock.

We may refer to this newly acquired

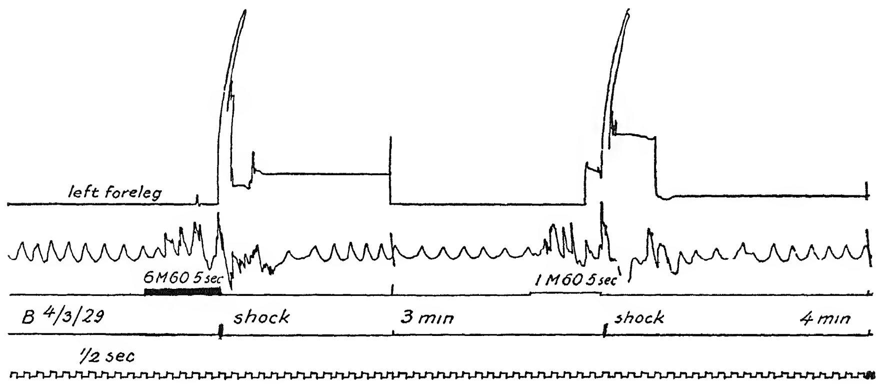


FIG. 5

response to the metronome as a habit, but when we consider it physiologically it is convenient to call it a conditioned reflex The sheep's behavior has been modified by a new situation in that the sound of a metronome now always precedes the electric shock. The animal has inherited defensive reflexes appropriate to painful

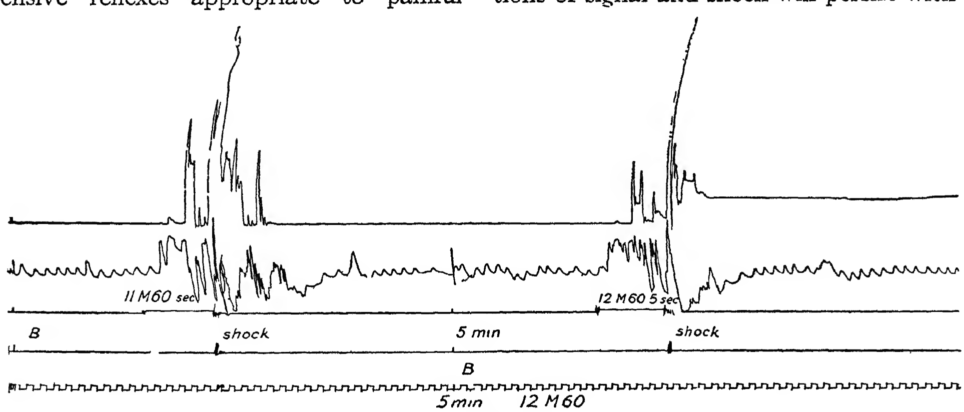


FIG. 6

stimuli applied to the skin but it has *learned* that a particular sound (the metronome) signals the approach of this annoying experience. From the physiological point of view, however, we are not interested in what the sheep thinks or feels. We are concerned only with the nature of the living machinery through which such a modification of behavior is made possible To explain this phenomenon we imagine the formation of new reflex connections in the brain in every way similar to the reflex arcs in the lower portions of the nervous system and try to picture to ourselves the processes involved in the construction of the new connections These acquired reactions have been found to be remarkably durable. In the sheep a conditioned reflex formed as the result of about one hundred combinations of signal and shock will persist without practice for a period of at least a year and a half.

The term "conditioned reflex" acquires added meaning when the conditions necessary for the disappearance of these acquired reactions are carefully investigated. The

following experiment can easily be performed. The sound of a buzzer precedes an electric shock to the foreleg one hundred times. An electric bell is then rung for the first time and the sheep at once lifts its leg, since the sound of the bell is somewhat similar to the buzzing But the bell is not followed by a shock As the bell is rung again and again without the shock the extent of the leg movement steadily diminishes in vigor and promptness and finally disappears. This is shown in Figure 7. All records reproduced in this chapter are to be interpreted in the manner previously described. Finally, the bell evokes but a slight change in breathing, while the buzzer arouses the usual vigorous conditioned leg movement. The completion of the experiment is shown in Figure 8. We can now say definitely that the animal discriminates the sound of the buzzer from the bell. Although it cannot speak it indicates unequivocally that it appreciates the difference between these two sounds. After all it must be remembered that speech is but a complex form of muscular reaction indicating processes in the brain hidden from direct observation.

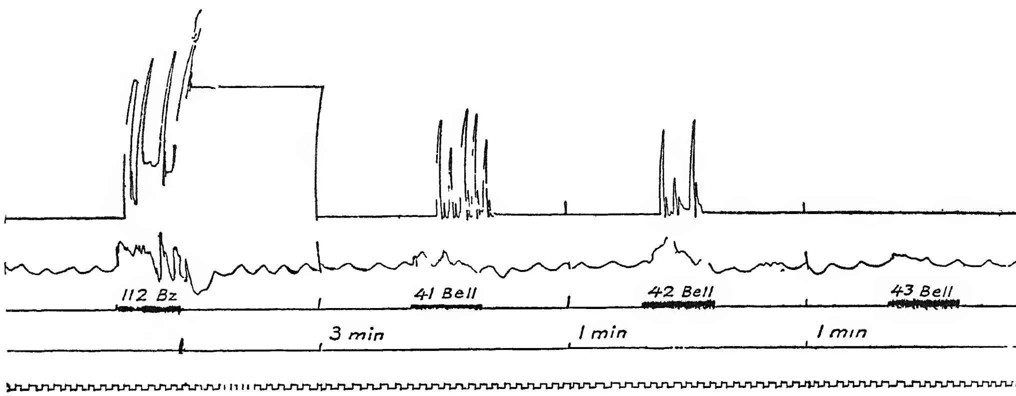


FIG. 7

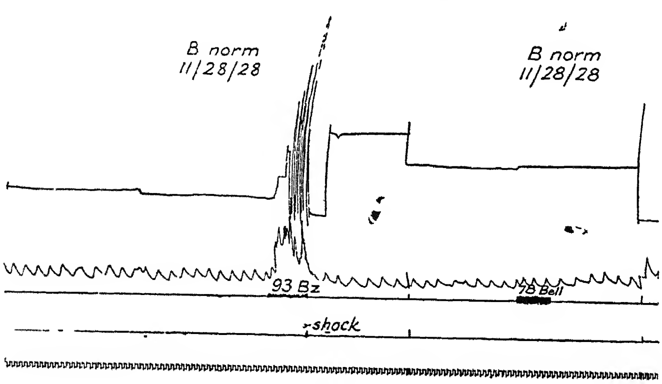


FIG. 8

Another question of fundamental importance for our understanding of the working of the brain can be answered through the use of this excellent method In a given animal species, which sensory mechanism is most delicate, i.e. which has the capacity for the most refined analysis of the environment? The approach to this problem can be illustrated from experiments with the sheep. If an electric shock is always preceded by the sound of the metronome beating 120 to the minute the animal will begin to raise its leg as soon as the metronome is heard. But if it is caused to beat 50 times per minute, unaccompanied by a shock, this particular rate will soon lose its significance as a signal of an approaching electric shock and will no longer evoke a leg movement. If the beats are increased to 60 per minute still without reenforcement by the shock this rate will also shortly fail to induce leg movements. The sound of the metronome at 72 beats per minute is then presented, again without the shock and again the sheep

learns to withhold its response (Figure 9). Finally the metronome beating 84 times per minute becomes a signal for *no shock* (Figure 10). From these records it is clear that the sheep can distinguish 120 from 84 beats per minute.

Similar tests can be made of the animal's vision. An electric light is placed on a tripod in front of the sheep and the current is turned on and off by a metronome acting as a simple electric switch (Figure 1). When the light flashes 160 times per minute a shock is always given and a conditioned reflex to the flashing light is eventually established. When the light flashes 50 times per minute it is unaccompanied by a shock, but, unlike the result of the previous experiment on sound, even after 128 presentations of the slowly flashing light with no shock and 235 tests of the rapidly flashing light followed by the shock, the sheep is still unable to discriminate between these widely different rates (Figure 11). The metronome which controls the flashing lamp is in the adjoining room and is, of course, quite inaudible to the sheep.

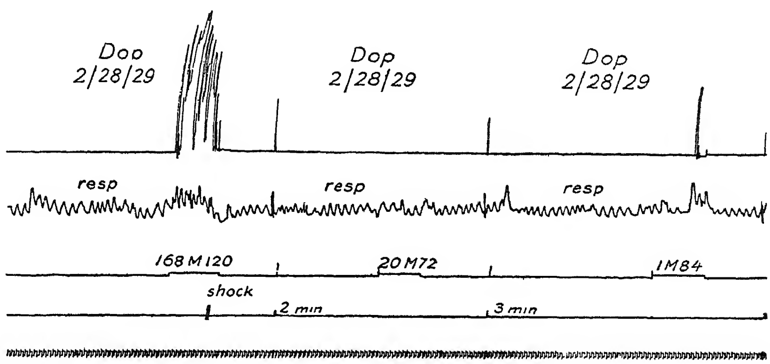


FIG. 9

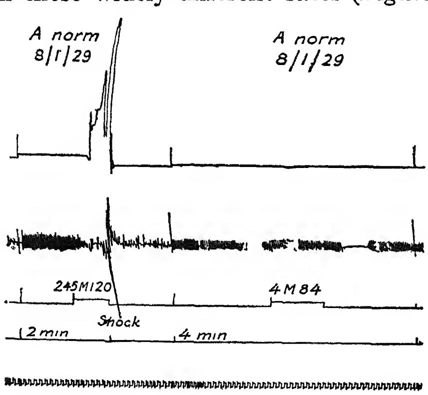


FIG. 10

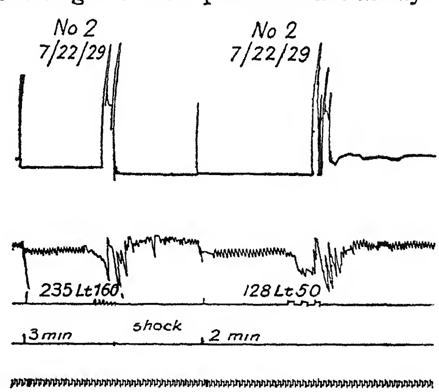


FIG. 11

Many other applications of this method and point of view in the study of intelligence could be mentioned, but the above examples illustrate the chief characteristics of this new type of physiological investigation.

Practical applications are inevitable The method described will make it possible to approach, through animal experimentation, the fundamental problems presented by the effects of injury and disease of the brain, the action of drugs on the central nervous system, the mental hygiene of work, relaxation and sleep, in addition to the many problems of education. Experiments are already in progress along these lines which promise a wealth of new information about such vital matters.

Although the answers which any real science gives to its problems are always incomplete they are usually definite and each answer suggests many new problems. To be sure, physiologists often give new names to familiar things, but in all progressive sciences the old and familiar becomes the new and unfamiliar through more careful and penetrating observation.

Science in Revolution (1765-1815) III

by JUSTUS SCHIFFERES

FOSSILS COME TO LIFE

IN many sedimentary rocks we can find parts or traces of the animals and plants that lived when the rocks were being formed. These relics of past geologic ages are known as fossils. They may be shells or other hard parts of animal bodies preserved in the rocks without chemical change. They may be the remains of animals or plants transformed into another substance (generally silica) through the action of mineral-bearing water seeping through the rocks. Or again, fossils may be imprints — molds left in the surrounding rock after the substance of the animal or plant has decayed and disappeared. The easiest fossil record to come by is a large lump of coal, in which we can often trace the leaves of some delicate fern that lived, grew green and died on this planet some millions of years ago.

Men have known of the existence of fossils since ancient times. Herodotus, Xenophon, Eratosthenes and others pointed out that great quantities of marine shells are to be found on land. Aristotle noted in his Meteorics, written about 330 B.C., that the fossil shells imbedded in layers of rock near the seashore were like the shells of living sea creatures that he could scoop up any day in his nets. He guessed, therefore, that sea and dry land at the shore line of continents and islands often changed places.

Generally in the Middle Ages and for several centuries thereafter it was believed that fossils were either unfinished models of God's handiwork or else the remains of creatures deposited on the land by the Deluge described in Genesis. This latter view was held by Dr. John Woodward, an ardent fossil-collector of the seventeenth century. In his Essay Toward a Natural History of the Earth (1695), he wrote: "Marine bodies were borne forth of the sea by the Universal Deluge and upon the return of the water back again from off the earth they were left behind on land."

Amer. Mus. of Nat. Hist.

The fossilized remains of *Ichthyosaurus quadriscissus,* found in Jurassic slate in Wuerttemberg.

There were certain dissenting voices. Leonardo da Vinci (see page 782), for one, disputed the Deluge theory. He had been employed as an engineer to drive some canals through stratified rock in northern Italy. In the rubble that his laborers' shovels turned up were the imprints of oysters, snails, clams and crabs almost exactly like those found in the nearby sea. He concluded that they had not been deposited by a single flood but that they were the relics of an age when ocean water had covered this part of the earth.

In the seventeenth century Nicolaus Steno (1638–87), a Danish churchman, physician and professor of anatomy, who was born Niels Stensen, also sought to read the riddle of the fossils. In an unjustly neglected work, Solids Contained within Solids (1669), Steno observed that "where shells and other similar deposits of the sea are dug up, these lands are sediments of the turbid sea." He thought it possible to estimate how often the "turbid sea" returned to cover the land by examining the rock layers. "When the lower strata were being formed, none of the upper strata existed," he concluded.

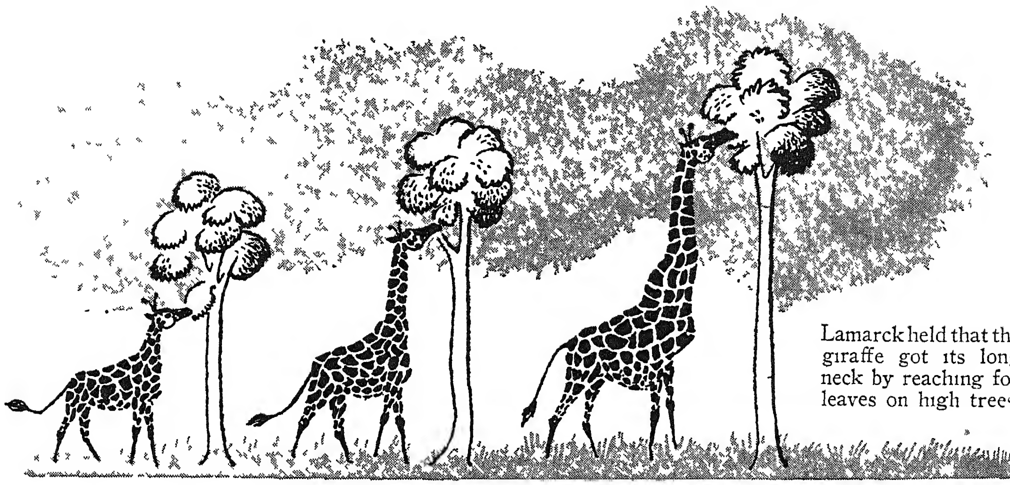
The Count de Buffon took fossils into account in discussing the formation of the

earth in his EPOCHS OF NATURE (see page 1665). He noted that fossil shells are abundant in every part of the earth He reasoned, therefore, that at one time the sea must have covered all the land, that fossils are the remains of creatures that lived in the sea and that were left on land when the waters subsided. These early creatures, he pointed out, were often quite unlike those that appeared later on the earth; he thought that it would be possible to study the history of the species that succeeded each other by making a thorough study of fossils.

By the first decade or so of the nineteenth century, interest in fossils had become widespread. Among the important fossil-hunters of the time were two eminent French scientists, Lamarck and Cuvier, who were fascinated by these relics of a remote past. Lamarck wrote a series of REPORTS ON THE FOSSILS IN THE VICINITY OF PARIS (1802–06), which are considered to be a model of accurate scientific writing Cuvier organized systematic hunts for fossils in the Paris area with

Bettmann Archive

Jean-Baptiste, Chevalier de Lamarck He arranged all living things, past and present, in one broad line, or "staircase," leading upward to man.



Lamarck held that the giraffe got its long neck by reaching for leaves on high trees

his friend Alexandre Brongniart; he carefully noted the strata, or rock layers, where they were found. Fossils played an important part in the teachings of both men.

The personal life of Jean-Baptiste, Chevalier de Lamarck (1744–1829), was a blend of tragedy and monotonous poverty. Born in Picardy, trained for the priesthood, commissioned a lieutenant on the field of battle for bravery, retired from the army on a pitifully small pension, Lamarck gained his livelihood for years as a poor literary hack, living a Bohemian life in the Latin Quarter of Paris. A book of his on the wonderful plant life of the Mediterranean coast won him the ear and friendship of Buffon, and a poorly paid position at the Jardin du Roi (Royal Gardens).

In 1793 Lamarck was appointed professor at the Jardin du Roi in a subject that he had never before studied: zoology. The rest of his life was devoted to study, thought and theorizing on the past and present course of living things — in one word, on biology. Blind in his later years, he was sustained principally by the loving care of his daughter Cornélie. "Posterity will honor you," she told him, and posterity has borne her out. Today biologists pay tribute to the man who invented the word "biology" to emphasize the kinship of living things, past and present.

Lamarck's name is inseparably linked with the origin of the theory of evolution. His evolutionary doctrine is contained in his masterpiece, ZOOLOGICAL PHILOSOPHY (1809). He arrived at this theory in a roundabout way. He started, like Linnaeus and other systematists of the eighteenth century, by attempting to classify the animal kingdom. But he realized, like Buffon, that animals and people exist as individuals and that any classification system involving them is an arbitrary — though useful — product of human thought. Any system of classification exists in man's mind, not in nature.

Lamarck was interested in the likenesses rather than in the differences between living things. The systematists had picked upon any slight difference between closely related plants or animals to find — and proudly announce — a new species. Lamarck saw that the more one studied the productions of nature, the more the so-called species merged into one another. He regarded it as highly improbable that the various species were forever fixed, as Linnaeus had maintained. Nature, thought Lamarck, was a creative force continually at work fashioning living creatures. It acted "as an intermediary between God and the various parts of the physical universe for the fulfilling of the divine will."

Lamarck arranged all living creatures, past (as shown in their fossil remains) and present, in one broad line or "staircase" leading uphill to the primates (higher apes and man). He sought to determine the

order in which these creatures came by noting the presence or absence of important organs, such as mammary glands, heart, lungs, legs and the like. Thus, he placed birds below mammals, which are naturally the highest order, because birds lay eggs and do not suckle their young (that is, they have no mammary glands). Cold-blooded reptiles he placed below warm-blooded birds because the reptiles have incompletely formed hearts and lungs. Snakes come below lizards because they have no legs; fishes are still farther down in Lamarck's "staircase" because they have lost their lungs. Below fishes are animals that have no backbone — the invertebrates. Lamarck patiently studied invertebrates; his classification of them is still in use.

After constructing a staircase or "ladder of nature," the next step is to explain the modifications of bodily organs that we find in this evolutionary line. Lamarck assumed that changes in the organs, forms and functions of animal bodies were brought about in order to meet the needs of a changed or changing environment. Thus, according to Lamarck, the giraffe got its long neck by reaching for leaves on high trees; the duck came by its webbed feet because it had to swim in order to find its prey; moles lost their eyes by living underground for several generations. Lamarck's explanation has been called a theory of "use and disuse"; provocative when first stated, it has long been discarded.

Lamarck's greatest error — the one that proved most damaging to his reputation — was the assumption that the new characteristics that animals acquire through their environment are directly passed on to their offspring. This assumption is not true, at least not in the way in which Lamarck meant it. We know now that generations of *blinded* moles will not produce *blind* moles.

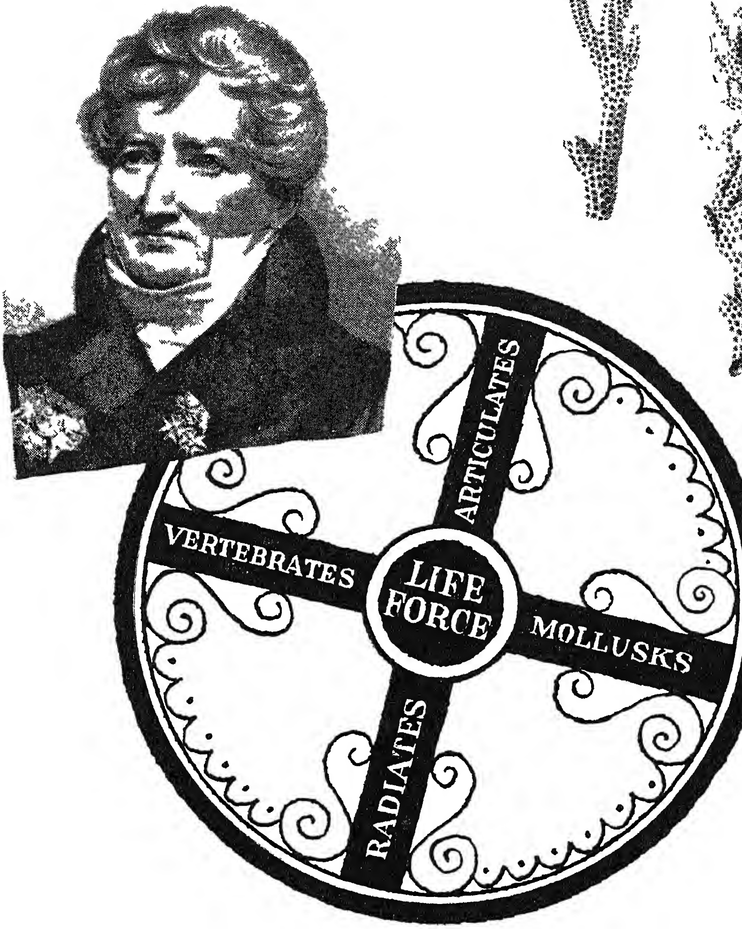
The evolutionary theory of Lamarck was warmly supported by Etienne-Geoffroy St. Hilaire (1772–1844), professor of geology at the Faculty of Sciences at Paris. Geoffroy St. Hilaire championed the theory in a series of famous and spectacular debates in 1830 on the floor of the French Academy of Science, but he was vanquished. His opponent in these debates was Cuvier, "dictator of biology" in Napoleonic and post-Napoleonic times, who firmly maintained the doctrine of the fixity of species.

Of all the natural scientists gathered in Paris at this time, none was more outstanding than the resplendent and hard-working fossil-hunter and system-builder Baron Georges-Léopold-Chrétien-Frédéric-Dagobert Cuvier (1769–1832). Few scientists have won greater honors in their lifetime. In the course of his illustrious career, Cuvier was professor of natural history at the College of France, perpetual secretary of the National Institute in the department of physical and natural sciences, chancellor of the University of Paris, grand officer of the Legion of Honor and a peer of France.

The bright son of a poor Huguenot family, Cuvier got the best part of his early education at an overwhelmingly strict German military academy at Stuttgart. He thrived, apparently, on the stern routine from which many less disciplined schoolmates (including the German poet Schiller) ran away. After completing his schooling, Cuvier became tutor to a family living on the channel coast of Normandy.

Like Aristotle, whom he studied and admired, Cuvier developed a love for biology at the seashore. Here he found innumerable lower animals — mollusks, worms, starfish — left stranded on the beach by the tide. Fascinated by the new world revealed to him in this way, Cuvier made an intensive study of his finds and drew accurate pictures of them. His drawings, which showed all the anatomical parts, were so clear and so ingenious that they won wide attention. Ultimately Cuvier was summoned to Paris and was appointed assistant to the professor of comparative anatomy at the Museum of Natural History.

Cuvier had never dissected a human body. For that very reason, perhaps, he succeeded in introducing a new approach to the study of anatomy — that is, comparative anatomy. By dissecting, studying, drawing and comparing the simplest



Baron Cuvier. He arranged all creatures in four classes: vertebrates, mollusks, articulates and radiates. He held that they were not directly connected but that all radiated from a central "axle" — the life force.

Above: four drawings of coral structures, taken from Cuvier's *Animal Kingdom Distributed According to Its Organization*

forms of life (rather than complicated forms like man), he was able to see and demonstrate the relationships between the separate parts of individual animals — for example, the relation of a lion's claws to his digestive system, as well as the mutual relations of the different animals.

Body organs do not exist alone; they are related to one another. If you find one part of an animal whose kin you have thoroughly studied, you can guess what the rest of the animal is like. Thus, when a man who knows birds well finds a bird feather, the size, shape and color of the feather will give him a good idea of the appearance of this particular bird.

Comparative anatomy offers a close parallel to scientific detective work. Given a clue like a fingerprint, a police expert can sometimes find a murderer. Cuvier, who knew a great deal about the anatomy of living creatures, was able to say, in effect: "Give me a tooth and I will reconstruct a whole animal."

This method obviously applies to long extinct animals, whose only visible remains are a fossil tooth or the fragment of a fossil bone. Cuvier created the science of paleontology by applying the methods of comparative anatomy to fossil fragments. He was able to show the kinship between elephants and other pachyderms, such as

the hippopotamus, the rhinoceros and the tapir. He did this by comparing the living forms with those that had become extinct long before and whose remains existed only in fossil fragments.

Cuvier maintained that the species that are now extinct had been wiped out in a long series of floods and other catastrophes; the last of these had been the Deluge described in Genesis. Not all animal life, he maintained, had disappeared in any one of these catastrophes. A few members of each of the species that still exist had found safety somewhere and had bred anew. There has been no change in species, he held, from one catastrophe to the other. According to this point of view, the existing members of the horse family are in no wise different from the first horses that appeared upon the earth.

In 1817 Cuvier published his ANIMAL KINGDOM DISTRIBUTED ACCORDING TO ITS ORGANIZATION. In this work he arranged all creatures, on the basis of their structure, in four classes: (1) vertebrates, (2) mollusks, (3) articulates (jointed animals) and (4) radiates (animals with parts symmetrically arranged around a central axis). These classes did not represent successive steps up an evolutionary staircase; rather, they were like the spokes on a wheel, which are not directly connected.

Cuvier remains a key figure in the history of science. He was the founder of modern comparative anatomy and of modern paleontology. A good deal of our present system of classification is based on his work. His influence upon the development of the evolutionary theory of the origin of species was also profound, though in a negative way. For such was his prestige that his doctrine of the fixity of species was to remain dominant for more than two decades after his death.

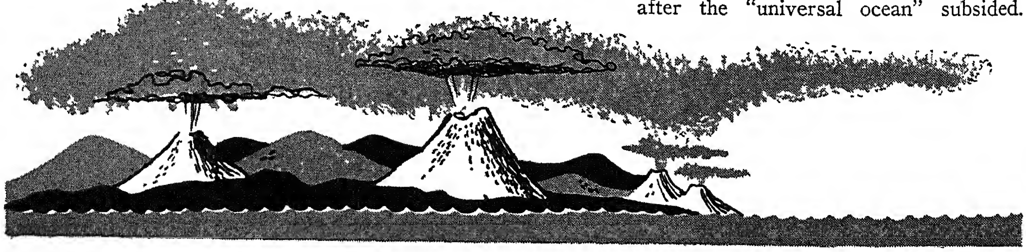
The great master of paleontology after the passing of Cuvier was Robert Owen (1804–92), director of the natural-history museum of the British Museum from 1856. Owen was an accomplished anatomist and a most prolific writer. A specialist in fossil teeth, he reconstructed such extinct creatures as the giant walking sloth and the huge bird called the "Diornis of New Zealand."

The study of fossils, then, threw a flood of light upon the living things that had once flourished upon the earth. This study proved to have another important application, for fossils furnish a clue to the age of the rock layers in which they are found. The clinching demonstration was made by William Smith, as we shall see.

THE STRUCTURE OF THE EARTH

One of the most fascinating pursuits of learned men in every age has been to speculate about the structure of the planet on which we live. Up to the eighteenth century very little was really known about the subject. Such bona fide knowledge of the science of geology as was then available was due, in the main, to the practical activities of mining engineers and miners, who were far more interested in digging for metals than in prying into the source and nature of rock formations that held valuable metal ores.

In the early years of the eighteenth century, the German philosopher-mathematician Gottfried Wilhelm von Leibniz



Buffon maintained that volcanoes came into action after the "universal ocean" subsided.

launched a new theory of the formation and structure of the earth. It was based upon certain speculations of Descartes (see page 856). Descartes had maintained that the earth was originally an incandescent mass like the sun, that it had cooled and that a solid crust had formed over a hot nucleus. In his PROTOGAEA (Prehistory of the Earth), which appeared in 1749, after the author's death, Leibniz argued that as the cooling process mentioned by Descartes continued, hollows would be formed within the crust of the earth. The crust would collapse in places where there were particularly large hollows; the solid parts of the crust would remain intact. As a result, there would ultimately be a succession of mountains and valleys.

The great French naturalist Buffon (see pages 1223-25) proposed a far more comprehensive theory of the origin and present structure of the earth in his EPOCHS OF NATURE, published in 1778. He attributed the origin of the earth (and of the other planets, too) to a collision between the sun and a wandering comet. In the formation of the earth, according to Buffon, there were seven epochs.

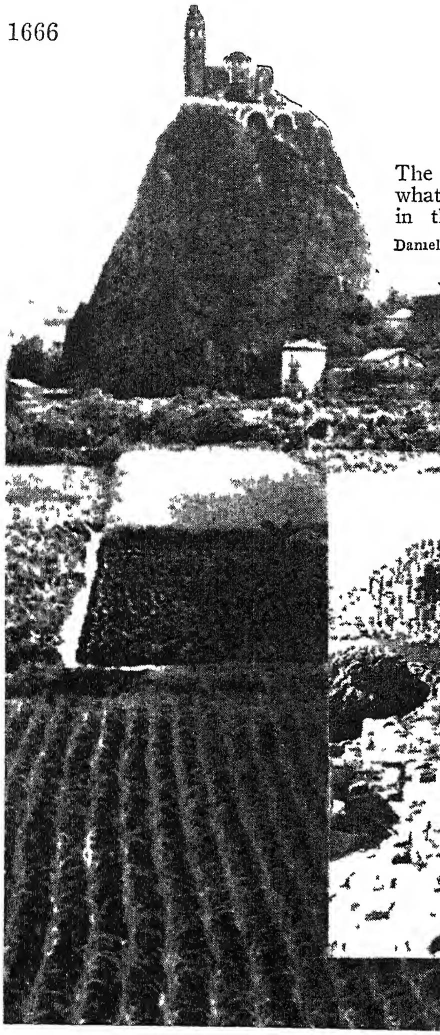
In the first, to which he assigned a period of 3,000 years, the earth was transformed, after the collision of the sun and the comet, from an incandescent gas to a molten mass. In the second epoch, requiring 32,000 years, great rents were formed in the crust of the earth and the principal mountain ranges came into being. In the third epoch, lasting 25,000 years, water covered the mainland and life began in the sediment of the "universal ocean." During the fourth epoch of 10,000 years, the waters subsided and violent volcanoes came into action. In the calmer period that followed — the fifth epoch, covering 5,000 years — elephants and other huge animals appeared and roamed over the polar regions, while vegetation began to push southward toward the still hot equator. In the sixth epoch, also lasting 5,000 years, the land mass was broken up into continents and man made his appearance. In the seventh epoch, which still continues,


Abraham Gottlob Werner, who proposed the so-called neptunist theory.

man won mastery over other living things; he will continue to reign supreme, says Buffon, until the earth cools and life becomes extinct. Buffon estimated the length of the seventh epoch at about 98,000 years.

Buffon's theory of the formation of the earth was incorrect in most details; yet it marked an important step forward. Perhaps the most significant thing about it was that it set the date of the earth's origin so far back in time. Today we know that the earth is much, much older than even Buffon had dared estimate.

As we have seen, Buffon assumed that at one time the waters covered all the land. This "universal ocean" was assigned an all-important role in the formation of the earth's crust in the subsequent doctrines of the learned Abraham Gottlob Werner (1750–1817). Werner was a slight, pug-nosed professor of mineralogy at the University of Freiberg, in Saxony, a part of modern Germany. He was one of the most self-assured men who ever lived. He was an eloquent and methodical teacher; he made the study of geology seem logical and simple (too simple, in fact). He attracted great numbers of students and his fame grew apace. Since he wrote almost nothing, many serious geology students felt that they must go to Freiberg to hear this cocky little professor utter the "final word" on geological topics. Werner eventually became the "dictator of geology"; he made the University of Freiberg one of the most famous in the whole world.



The Puy-de-Dôme, an extinct volcano in what was once the province of Auvergne, in the south-central part of France.

Daniell, from Monkmeyer

The Giant's Causeway, in Northern Ireland. It is a formation of basalt columns — a result of volcanic activity.

Philip Gendreau

He had observed that in the mine shafts in Saxony the earth generally showed a series of very definite strata (layers; the singular form is stratum). Werner was a stay-at-home who had never traveled out of his native province; he assumed that rock strata everywhere on the face of the globe had been laid down in the same order and at the same time as the strata of Saxony. To explain their formation, he assumed that ocean waters had covered the earth periodically. Layers of sand had then settled to the bottom of these oceans. There they had been shaped into mountains and valleys, which were revealed as the waters subsided. When the ocean rose again and subsided again, another stratum of mountains and valleys would be formed. The various layers of the earth, according to Werner's teachings, fitted one within the other like the skins of an onion. Because the globe, as Werner conceived of it, had been fashioned by a series of universal floods, his theory was called neptunism, after Neptune, the Roman god of the sea; his followers were known as Neptunists.

The neptunist theory foundered on the rock called basalt, which Werner and his followers could never explain satisfactorily. An enormous number of fossils are found in sedimentary rock, but none has ever been found in basalt. It is hard, therefore, to think of it as formed by the settling sediment of an ocean. The first hint as to its real formation came from Jean-Etienne

Guettard (1715–86), a Paris-trained physician, who became curator of the natural-history museum of the Duke of Orleans.

As a boy Guettard made field trips throughout France to collect botanical specimens. His interest gradually shifted from the plants themselves to the rocks over and near which they were found. He then began to make maps showing the distribution of mineral-bearing rocks in central and northern France. Extending his activities, he traveled on foot through southern France and came to the province of Auvergne.

As Guettard counted off the weary miles along the road, his attention was drawn to the milestones, which were of a peculiar black color. The thought came to him that they might be "fire rocks," of volcanic origin. He found that the milestones had come from a quarry at Volvic. The very name of this town seemed to confirm Guettard's suspicion. It is apparently an abbreviation of *Volcani Vicus* — Vulcan's Village, in Latin; since Vulcan was the Latin god of fire, did not Vulcan's Village really mean Volcanic Village?

Guettard noted that the rock in the quarry looked like a solidified stream of lava, and he was able to make out the cone and crater of a typical volcano. He investigated other areas in Auvergne and at last was able to show that the rounded hills of that province were really a string of extinct volcanoes. Later he noted that a good deal of basalt was found in these volcanic areas. He failed, however, to draw the seemingly obvious conclusion that this basalt was produced by volcanic activity. As a matter of fact, he maintained that it was formed by "crystallization in an aqueous fluid" (that is, water).

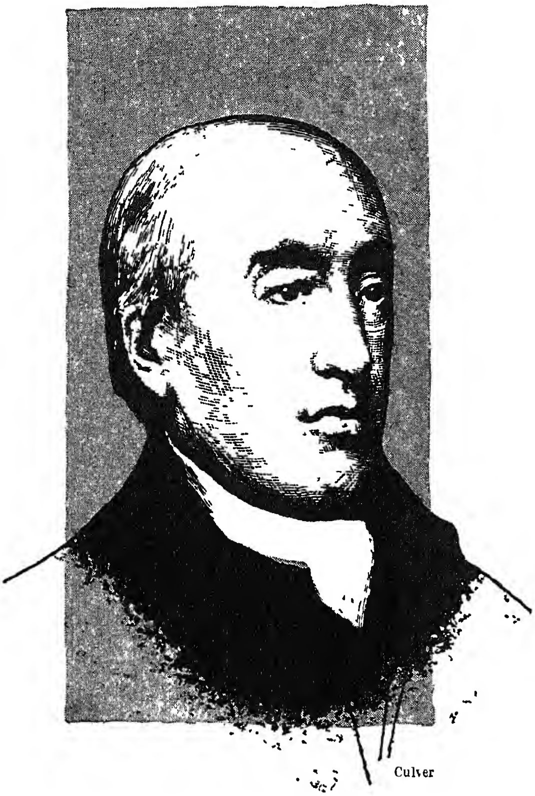
The correct explanation of basalt was supplied by Guettard's ascetic compatriot, Nicholas Desmarest (1725–1815). A poor but brilliant youth, Desmarest rose to be inspector general and director of manufactures of France. Eventually his life was saved by his hobby, geology. He had been in the habit of making field trips on foot, sleeping in shepherds' huts and sharing their simple diet of bread and cheese. Hence the authorities, during the Reign of Terror of the French Revolution, could not be persuaded that wealthy Desmarest was truly an aristocrat, meriting death on the guillotine.

Desmarest, like Guettard, had explored Auvergne on foot and had been lucky enough to come upon natural columns of basalt. He argued that rocks like these could not possibly have been laid down as ocean sediment. He became convinced that basalt was an igneous rock, resulting from the action of heat within the earth; that it was, in fact, a finely fused kind of lava, a product of volcanic origin.

Desmarest believed that volcanic activity accounted for far more of the earth's rocks than even Guettard had suspected. He studied the literature dealing with the Giant's Causeway, a spectacular formation of basalt columns in Northern Ireland. He concluded that there had once been active volcanoes in this part of the globe. Volcanic activity, he suggested, had caused hot lava to be pushed up between the cracks and fissures of overlying sedimentary rocks, which had been laid down by the sea. This lava had then solidified in the form of basalt.

Desmarest's theories were eagerly adopted by a number of other geologists. Entranced by this dramatic theory of volcanic action, they attributed altogether too much importance to the action of volcanoes in the formation of the earth. These extremists came to be known as Vulcanists.

A far more logical and better-rounded theory of rock formation was soon put forth by James Hutton (1726–97), an estimable "private gentleman" of Edinburgh, son of the city treasurer. He had received medical training at Paris and Leyden. But he forsook the practice of medicine for numerous other interests, including farming, chemistry, the study of scientific method, and geology. He invented a process for the manufacture of sal ammoniac and made an independent fortune; thereafter he devoted his life to travel and study. Hutton was one of the founders of the Royal Society of Edinburgh, the Scottish counterpart of the Royal Society



James Hutton, author of *The Theory of the Earth* and founder of the plutonist school.

of London, discussed in previous pages.

Hutton's magnificent, though exceedingly obscure, THEORY OF THE EARTH was the result of thirty years of wandering and meditation; it was published in 1795, just two years before his death. For Hutton, the earth has "no vestige of a beginning, no prospect of an end." It is a world in which all phenomena can be accounted for by natural causes that are still in operation and that will continue to operate for all time. This idea has been called the principle of "uniformitarianism."

Hutton embraced the truths in the neptunist and vulcanist systems, but he discarded their fanciful notions. The essence of his theory is this: (1) The solid earth has risen above the surface of the seas and into contact with the atmosphere as a result of fire or heat, deep below the crust of the earth, which has the power to melt and expand solid bodies. But (2) "there is a necessary principle of dissolution and decay . . . moving powers by which the summits of our land are constantly degraded [worn down by erosion]. The materials of the decaying surface are carried toward the coast by rains and rivers that pour at last their mighty waters into the ocean." These are the forces of erosion that most visibly sculpture the landscape; they also account for the laying down of sedimentary rock. Thus the earth, "like the body of an animal, is wasted at the same time that it is being repaired" Finally (3) "in the ocean there is a system of animals (for example, corals) which have contributed materially to the formation of our land."

Because Hutton's theory involved the upthrust of mountains from the depths of the earth, it has sometimes been called plutonism, after Pluto, the Greek god of the lower world. Plutonism accounted for every kind of rock and rock formation that could be found in the world. Among other things, it offered a detailed explanation of the formation of basalt. Hutton pointed out that basalt is a rock whose inner structure has been changed from that of coarse lava by the action of heat and pressure; under similar conditions the sedimentary rock limestone yields marble. Today we call rocks like basalt and marble metamorphic ("changed afterward": referring to the fact that they were fashioned anew after being first laid down).

The fruitful ideas contained in Hutton's THEORY OF THE EARTH were so obscurely set forth that the work ran the risk of being neglected by scientists and laymen alike. Fortunately Hutton's good friend, the Scottish mathematician John Playfair (1748–1819), restated the plutonic theory in a "consummate masterpiece of scientific writing," which he modestly entitled ILLUSTRATIONS OF THE HUTTONIAN THEORY OF THE EARTH (1802).

Playfair added another earth-sculpturing factor — glaciers. For him they were "the most powerful engines without doubt that nature employs" for the removal of large masses of rock. The full importance of glaciers, however, was not recognized until the 1830's when the Swiss geologist Louis Agassiz showed that they had once covered much of Europe. Later he dem-

onstrated that large parts of North America, too, had once been covered by glaciers

The theory of plutonism was fiercely assailed by the Neptunists. They argued that basalt could not possibly have been formed from heated lava, because when molten lava cools it becomes smooth and brittle like glass and not crystalline like basalt. They also said that heated limestone would turn to quicklime, as Joseph Black had already pointed out, and not to marble.

Another friend of Hutton's, Sir James Hall (1761–1832), the father of experimental geology and the president of the Royal Society of Edinburgh, now did battle with the Neptunists. By means of a series of ingenious laboratory experiments, he proved that the objections to the Huttonian theory were unfounded. He showed that "in consequence of the combined action of heat and pressure, effects were produced different from those of heat on common occasions."

When Hall heated limestone under pressure in a plugged gun barrel, it turned to marble, not quicklime, as the Neptunists had claimed. Lava from Mt. Etna and whinstone from Scotland, melted in the high heat of the reverberating furnace of a nearby iron foundry, could be turned either into smooth, black glass by *quick* cooling or into crystalline, basaltlike rock by *slow* cooling. The idea that the rate of cooling would change the character of the product had been suggested to Hall by the report of a strange occurrence in a green-bottle-glass factory at Leith. A potful of glass mix had been spoiled by *slow* cooling, but it had been made into fine-quality glass by reheating and *quick* cooling.

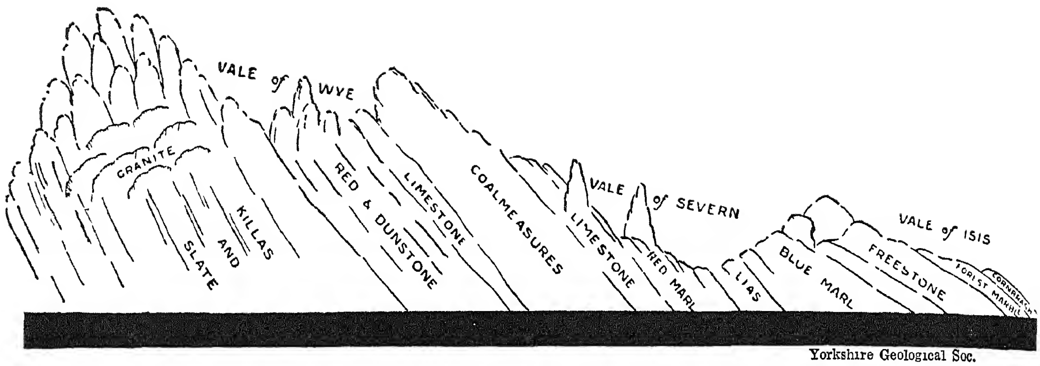
By 1810 the modern theory of rock formation had been pretty definitely worked out. Great progress had also been made in stratigraphy, the study of the arrangement of rock strata. In his THEORY OF THE EARTH, Hutton had suggested that the strata had been laid down in orderly fashion during a long period of years. These strata, he maintained, had once been the beds of seas, lakes and other bodies of water. However, it was the English surveyor, canal-digger, engineer and land appraiser William Smith (1769–1839) who did most to reveal the nature and the arrangement of the different layers of earth. Because of his remarkable contributions to stratigraphy, his acquaintances gave him the partly mocking, partly affectionate nickname of "Strata Smith."

Smith plodded on foot over much of the English countryside in Oxfordshire, Gloucestershire and Warwickshire, looking for strata that would hold water for canals, telling coal miners where to dig for coal and shrewdly appraising the value of farm land by the character of the fossils found in the rocks underneath it. Eventually he came to see that the same kinds of fossils always occurred in the same strata.

Smith now began to work on the project of identifying the different strata by means of their fossil remains. Fortunately for him and for the science of geology, the layers of sedimentary rock in the English countryside had generally been laid down "like so many slices of bread and butter." We can tell which layer of rock was formed before which other layer because we know the difference between up and down; the older rocks, as you see them on a cliffside, are underneath. The most recent fossil remains are found, naturally, in the surface layers. Smith learned to identify the layers corresponding to different fossil deposits. As a result he was able to identify strata in places where the order of formation was not evident.

Smith presented his findings in his STRATIGRAPHICAL SYSTEM OF ORGANIZED FOSSILS (1817). He also published a number of geologic maps showing the arrangement of strata in the English countryside. In 1831 the Geological Society of London awarded him a medal "for being a great and original discoverer in English geology; and especially for his having been the first to teach the identification of strata, and to determine their succession by means of their embedded fossils."

The science of geology definitely came of age in the early 1830's. This period saw the publication of the PRINCIPLES OF



Yorkshire Geological Soc.

Sketch of the succession of strata, from a geological map by W. Smith.

GEOLOGY (1830–33), in three volumes, by the Englishman Sir Charles Lyell (1797–1875) Lyell had studied for the bar and practiced law for a time, but in 1828 he abandoned his legal career in order to devote himself to geology. His merits as a scientist were soon recognized and he won many honors in the course of his long lifetime. In his later years he was one of the most ardent supporters of Charles Darwin, whose theory of evolution we shall discuss in another chapter. Lyell was buried in Westminster Abbey.

The PRINCIPLES OF GEOLOGY represented a masterly summing up of all the important geological work done up to the author's time Lyell presented new facts and corrected old errors. He demolished once and for all the theory that floods or other catastrophes had been the principal agent in fashioning the landscape. "The land," he said, "has never in a single instance gone down suddenly for several hundred feet at once . . . Great but slow oscillations brought dry land several thousand feet below sea level and raised it thousands of feet above." Lyell gave powerful support to Hutton's theory of uniformitarianism. He pointed out that the building of mountains, the formation of rocks, the warping and breaking up of strata and even the fossilization of animals and plants are still going on as they did in the earlier ages of the earth.

THE NATURE AND ORIGIN OF THE UNIVERSE

While geologists were finding the correct explanation of the formation of the earth, astronomers were busily ferreting out the secrets of the origin of the universe, of which the earth is but a part. In the Age of Revolution two men of genius — Herschel and Laplace — made especially notable contributions to the study of astronomy. Sir William Herschel, a German-born naturalized British subject, presented a new and exciting concept of the immensity of the universe. A French nobleman, the Marquis de Laplace, supporting Newton's teachings, offered a plausible theory of the formation of the solar system.

Herschel was born in 1738 in Hanover, Germany; his name in German was Friedrich Wilhelm Herschel. The son of an oboe player in the Hanoverian Guards, young Herschel originally chose music as his career; he joined the band of the guards at the tender age of fourteen. Five years later he came to England in order to seek his fortune as a musician. In 1766 he became organist at the Octagon Chapel in Bath, and he brought his sister Caroline to England to live with him.

The young musician became greatly interested in astronomy and built a number of powerful telescopes. He was scanning the heavens with one of them in March 1781 when he saw a heavenly body — perhaps a comet, he thought — showing an appreciable disc. This "comet" proved to be the planet Uranus, the first new planet to be discovered in historic times. Overnight Herschel became famous. He was awarded a fellowship in the Royal Society of London and won the society's Copley Medal; in 1782 George III made him royal astronomer with a stipend of £200 a year. Herschel soon moved to Slough, where he

lived with his devoted sister Caroline until his death in 1822. Caroline was a capable astronomer in her own right; she discovered eight comets and a number of nebulae.

Herschel's chief contributions to astronomy were contained in a series of papers written for the PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY from 1780 to 1821. One of the greatest observational astronomers who ever lived, he conceived of a vast "star-gauging" project; he sought to determine how the stars were distributed in space by focusing a telescope upon each part of the sky in turn. He found great variations of density; in some areas the telescope revealed over 500 stars; in others, but a single one.

The stars were, of course, particularly dense in the part of the sky that had been known for centuries as the Milky Way. Herschel's observations led him to believe that the Milky Way formed a "stratum of stars," roughly in the form of a long, rectangular box, one end of the "box" being split so as to form two separate parts. The sun, he held, was set within the "box," but not at the exact center. Later, Herschel adopted the theory that forms the basis of modern belief: that the Milky Way has the form of a double convex lens, with the sun somewhere in the central plane separating the two halves of the lens.

Herschel laid the foundation for other modern astronomical beliefs. He thought of the Milky Way as an island universe, set in the immensity of space. It was not, in his opinion, unique; he thought that the spiral nebulae were also island universes, each forming a complete system of stars. Herschel was among the first to conceive of a growing, changing and expanding universe; he tried to show how the heavenly bodies were evolving from diffuse matter and irregular clouds in space to glowing stars. He compared the heavens to a "luxuriant garden which contains the greatest variety of productions in different, flourishing beds."

Unlike Herschel, who started out by being a gifted amateur in science, Pierre-Simon, Marquis de Laplace (1749–1827), received a thorough scientific education, becoming particularly proficient in mathematics. He held the post of professor of

Sir William Herschel and his largest reflecting telescope.

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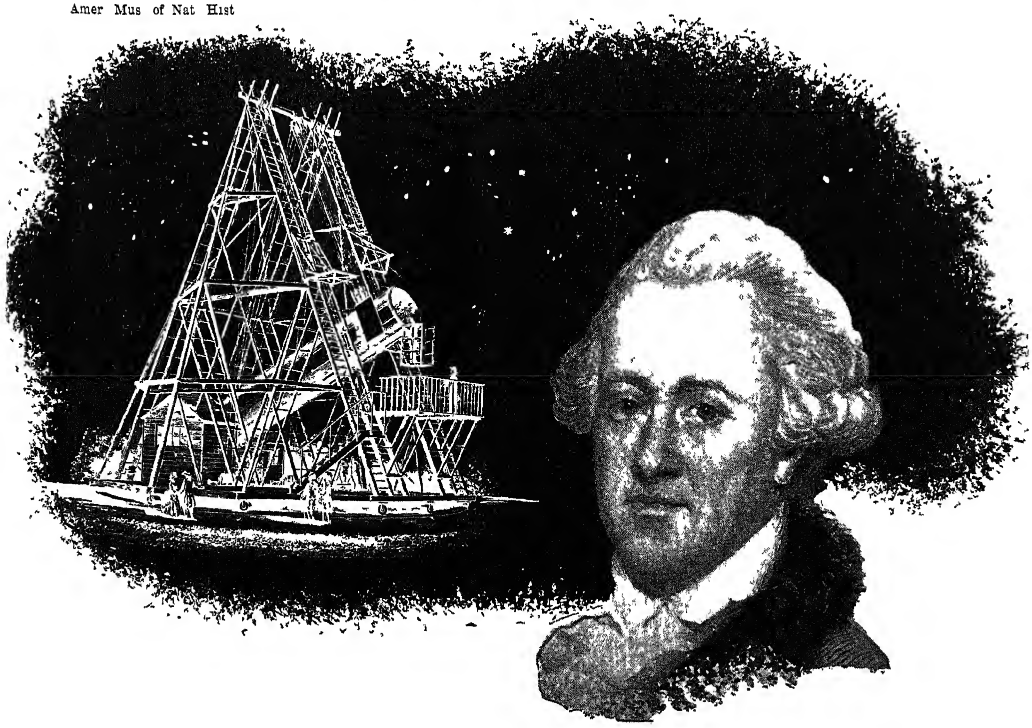


mathematics at the Military School in Paris, and he enjoyed a number of other official positions under the different governments that flourished in France during his lifetime.

His greatest work was his CELESTIAL MECHANICS, published in five large volumes from 1799 to 1825. It represented a restatement of the PRINCIPIA of Newton, richly and logically extended and enlarged. It was a precise, self-assured work, in which the Newtonian concept of the heavens was set forth as a self-evident fact. In this icily logical survey there was not a single mention of a Supreme Being. Laplace was chided for his omission by Napoleon, who asked how a book that proposed to explain the universe could avoid mentioning the name of the Deity. Laplace said: "I had no need for that hypothesis." The Emperor retorted: "It is nevertheless a beautiful hypothesis and explains many things."

Laplace likewise formulated a so-called nebular hypothesis in order to explain the motion of the planets. It was presented, not in his CELESTIAL MECHANICS but in his EXPOSITION OF THE SYSTEM OF THE WORLD, written in a more popular vein. Why, asked Laplace, did the sun, the planets and their satellites (at least those known at that time) turn in the same direction and move in very nearly the same plane? He answered the question in terms of "nebulae" and the nebular hypothesis, which we shall now explain.

Look up in the sky some night and you will see a mist around the moon. (Actually the mist is water vapor and exists in the earth's atmosphere many thousands of miles away from the moon.) When the astronomers of the eighteenth century looked at their stars through their not very powerful telescopes, they saw that the stars were often surrounded by faint, cloudlike, self-luminous mists, looking something like the "mist" around the moon. They called these misty clouds "nebulae."

Laplace knew that our sun is also a star. He therefore advanced the theory that once upon a time, eons ago, our sun was surrounded by just such a nebulous cloud. This cloud extended beyond the surface of the sun to a distance greater than that of the last (then known) planet, Uranus. The cloud, spinning with the sun, just as our atmosphere spins with the earth, was very hot. But gradually it grew cooler around the edges, and the hot gases composing it condensed. "We may therefore suppose," wrote Laplace, "that the planets were formed at successive limits of the sun's atmosphere by the condensation of zones of gases (that is, nebulae) which the sun, while cooling, must have abandoned."

Laplace's nebular hypothesis was widely accepted by astronomers and remained in vogue for over a century. Today it is no longer regarded as an adequate explanation of the formation of the solar system. Yet none of the theories that have been proposed in its place has been universally accepted; the origin of our earth and the other planets remains a mystery.

THE RISE OF PREVENTIVE MEDICINE

Throughout the centuries that we have been discussing, disease was a constant threat to the men, women and children dwelling upon the earth. The plague returned especially often to strike terror to the hearts of all. The theories that were then current concerning the cause of disease and the spread of epidemics left little reason for hope. Then, quite suddenly, toward the end of the eighteenth century, there was a drastic change in the situation. A new method of preventing and controlling the dread disease of smallpox was introduced, and this aroused new hope for the development of a genuine science of preventive medicine.

Smallpox, which we now recognize as a virus disease, was already known in antiquity to certain peoples, including those of Egypt and India. It was not introduced into Europe until about the tenth century and did not reach epidemic proportions there until a long time afterward. By the eighteenth century, however, its ravages

were so widespread that it was commonly regarded as one of the most terrible scourges of mankind. In that century some sixty million people died of the disease in Europe alone; it caused one death out of every ten. Those who survived it were often left horribly disfigured. Pockmarks were a common sight in those days. If the face of a fugitive from justice were entirely free of such marks, that mark of identification was duly stressed in advertisements for his arrest.

For many years it had been realized that those who had recovered from smallpox were immune from further attacks — that even those who had had a mild attack acquired immunity. The practice had grown up in the Middle East, therefore, of purposely infecting (or, as we would say today, inoculating) a person with pus taken from a smallpox sore. Generally this brought on a mild attack of smallpox, and immunity resulted.

Inoculation as a preventive against smallpox was introduced into England in the early years of the eighteenth century by the much-traveled Lady Mary Wortley Montagu, renowned for her brilliant and sometimes scandalous letters. Lady Mary became familiar with the practice of inoculation with smallpox while she lived in Constantinople, where her husband was the British ambassador. "Everywhere [in Turkey] thousands undergo the operation," she wrote to a friend, "and the French ambassador says pleasantly that they take the smallpox here by way of diversion, as they take the waters in other countries."

Lady Mary had her small children inoculated against smallpox and she urged the Princess Royal to immunize her own children in the same way. The Princess consented only after six condemned criminals in Newgate Prison had permitted themselves to be inoculated and had survived the ordeal without disastrous effects. (Thereby they won their freedom.) In the following years of the eighteenth century the practice of inoculation with smallpox became quite popular. It was realized in the course of time, however, that certain dangers were involved. For one thing, infection would sometimes spread from an inoculated person to a whole community. Then, too, an inoculated person would occasionally develop a virulent form of the disease.

Toward the end of the century an English country doctor, Edward Jenner (1749–1823), became interested in finding a safer and better way to control the scourge of smallpox. Jenner had studied in London under the great physician and anatomist John Hunter and had returned to his native Gloucestershire to practice medicine. He was struck by the fact that

Bettmann Archive

Edward Jenner performing the first vaccination.

The supposed effects of vaccination, from a famous cartoon by J. Gillray.

some people who were inoculated with smallpox had no reaction whatsoever. He found that many of these people had had cowpox, a mild disease that attacks both cows and humans. In the country district where Jenner lived, popular belief had it that dairymaids who caught cowpox from the cows they milked never contracted smallpox. After careful investigation, Jenner found that in this case, at least, popular belief was based upon sober fact.

He now tried a daring experiment. He took some pus from a sore on the arm of a milkmaid suffering from cowpox and he injected the pus into the arm of a healthy eight-year-old boy, James Phipps. The boy had a comparatively mild reaction and quickly recovered from the effects of the inoculation. Then Jenner tried to inoculate young Phipps with smallpox, but the lad did not catch the disease.

Two years later (1798) Jenner published his famous INQUIRY INTO THE CAUSE AND EFFECTS OF THE VARIOLAE VACCINAE (Cowpox). In it he revealed how he could prevent smallpox by vaccination — that is, by inoculation with vaccinia, the technical name for cowpox. (Today the word "vaccination" has come to mean almost the same thing as "immunization," or inoculation against any infectious disease.)

Jenner's INQUIRY met with a mixed reception. Some persons violently opposed vaccination because they objected to one human being deliberately infecting another with disease. Others seriously maintained that those who were vaccinated would become cowlike — that they would sprout horns and grow a tail! In the very year that the INQUIRY was published, an anti-vaccination society was organized in order to combat Jenner's ideas.

Fortunately, however, more enlightened people hailed Jenner's discovery with enthusiasm. A Royal Jennerian Society was founded in London, in 1803, to further the cause of vaccination. In a period of eighteen months twelve thousand persons were inoculated in London under the auspices of the society; the number of deaths from smallpox in the city dropped amazingly. Jenner was voted £30,000 by the British Parliament as a token of gratitude.

He also won wide acclaim abroad. Napoleon had a mass vaccination performed on all the French troops who had not yet had smallpox; later, in deference to Jenner, he released a number of English civilians who had been detained in France. In America, Benjamin Waterhouse, professor of physick (medicine) at Harvard, was an ardent supporter of Jenner; he undertook to prove the safety and effectiveness of vaccination by using his own children as subjects. Even the Indians of North America acclaimed the English physician. In 1812 a tribe sent him a gift of a belt and a string of wampum by way

of thanks for saving them from what had been one of the greatest scourges of their people.

The science of preventive medicine was thus fairly begun. Its greatest triumphs have been won over the diseases for which, as in the case of smallpox, a specific method of prevention has been made possible. Immunization has proved effective, not only against smallpox but against a host of other diseases, including diphtheria, scarlet fever and whooping cough.

THE HAUNTING PROBLEM OF OVERPOPULATION

It was a favorite notion of certain philosophers of the eighteenth century that by following the dictates of reason men could establish an ideal and nearly perfect form of society, in which everyone would be truly happy. But in the year 1761 a Scottish scholar, Robert Wallace, struck a jarring note. In a treatise called VARIOUS PROJECTS OF MANKIND, NATURE AND PROVIDENCE, Wallace claimed that the establishment of an ideal state might well lead to disaster. If war, poverty and general misery were abolished in such a society, "mankind would increase so prodigiously that Earth at last would be overstocked."

After all, according to Wallace, the fertility of the earth is not boundless but is subject to certain very definite limits. If mankind "increased prodigiously," there would not be enough for all, and the result would be hunger, rioting and general chaos. To be sure, he pointed out, mankind might solve the problem by adopting certain drastic measures: by limiting the number of marriages, by sterilization, even by homicide. But he doubted whether such regulations could be put into effect.

Toward the end of the century the thesis of the dangers of overpopulation was taken up again by a young English clergyman and economist, Thomas R. Malthus (1766–1834), who was educated at Oxford and took orders in 1797. Malthus had had some heated discussions with his father about the establishment of a perfect form of society. The father believed that such a development was perfectly possible. But his son denied this, for, he maintained, the population tends to increase faster than the available food supply and therefore must be constantly checked. To bolster up his arguments, the younger Malthus made a careful study of population growth and found what he considered to be decisive backing for his position. In the year 1798 he published the results of his research in his ESSAY ON THE PRINCIPLE OF POPULATION. He brought out an augmented second edition of the work in 1803; four other revised editions appeared during his lifetime.

Malthus tells us that he got the idea for the ESSAY from a remark made by Benjamin Franklin, in 1751, to the effect that "there is no bound to the prolific nature of plants and animals but what is made by their crowding and interfering with each other's means." We can give some idea of Malthus' clearly expressed and most melancholy theory by setting down a series of excerpts from the ESSAY:

"I think I may fairly make two postulates:

"First, that food is necessary to the existence of man:

"Secondly, that the passion between the sexes is necessary and will remain in nearly its present state.

"These two laws ever since we have had any knowledge of mankind appear to have been fixed laws of our nature. I do not know that any writer has supposed that on this earth man will ultimately be able to live without food. Toward the extinction of the passion between the sexes no progress whatever has hitherto been made.

"Assuming then my postulates as granted, I say that the power of population is indefinitely greater than the power in the earth to produce subsistence for man.

"Population, when unchecked, increases in geometrical ratio.* In the United States of America, the population has been

* For the difference between geometrical and arithmetical "ratio," or progression, see page 1076.

found to double itself in twenty-five years. [This figure was for the seventeenth and eighteenth centuries.]

"Subsistence increases only in arithmetical ratio. If the subsistence for man that the earth affords was to be increased every twenty-five years by a quantity equal to what the whole world at present produces, this would allow the power of production in the earth to be absolutely unlimited, and its ratio of increase much greater than we can conceive that any possible exertions of mankind could make it.

"Taking the population of the world at any number, a thousand millions for instance, the human species would increase in the ratio of 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, etc., and subsistence as 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, etc. In two centuries the population would be to the means of subsistence as 512 to 10; in two thousand years the difference would be almost incalculable.

"By that law of our nature which makes food necessary to the life of man the effects of these two unequal powers must be kept equal.

"This implies a strong and constantly operating check on population from the difficulty of subsistence. This difficulty must fall somewhere; and must necessarily be . . . felt by a large portion of mankind.

"Throughout the animal and vegetable kingdom Nature has scattered the seeds of life abroad with the most profuse and liberal hand. She has been comparatively sparing in the room and nourishment necessary to rear them. Necessity, that imperious all-pervading law of nature, restrains them within the prescribed bounds.

"I see no way by which man can escape from the weight of this law which pervades all animated nature. No fancied equality, no agrarian regulations in their utmost extent, could remove the pressure of it even for a single century. And it appears, therefore, to be decisive against the possible existence of a society, all the members of which should live in ease, happiness and comparative leisure, and feel no anxiety about providing the means of subsistence for themselves and families."

Malthus foresaw that scientific progress would bring about increased agricultural production. But he held that this increase would never suffice to provide subsistence for all the possible future offspring of mankind. That is why, according to his theory, checks are necessary. Some of these checks are preventive; they consist of limiting the birth rate by celibacy, deferred marriage and contraception. Others are positive; these include war, famine and misery. Since checks are necessary in any event, Malthus urged men to seek the use of preventive checks, which he considered as the lesser of two evils.

The Malthusian theory has found ardent supporters and just as ardent opponents ever since it was enunciated, and its basic thesis is still being debated. The opponents of the theory claim that the scientific and technological advances in the nineteenth and twentieth century have added enormously to the food resources of mankind. After all, they say, the population of the world has increased more than twofold since Malthus published his Essay, and yet the general level of living has gone up.

The supporters of Malthus concede that the population of the world has increased by leaps and bounds and that many enjoy a higher standard of living. Yet they point out that there is still no lack of misery or vice or pestilence or famine. One check on population—disease—has certainly been made less effective as a result of scientific progress in preventive and curative medicine. On the other hand, modern science has produced instruments of war, like the atomic bomb, that are far more destructive than earlier weapons. The system of checks, therefore, is still functioning.

Can human wisdom put a check on population without resorting to war? Can science keep pace with increased population by making man's fields more fertile, by making habitable the waste areas of the earth, by aping the ability of green plants to manufacture food in the presence of sunlight? Until these questions can be answered in the affirmative, the debate over the Malthusian theory will continue.

SCIENCE THROUGH THE AGES is continued on page 1766.

THE AIR IN WHICH WE LIVE

Where the Atmosphere Came From — Its Height, Importance, Composition, Permanence

AN INDISPENSABLE CONDITION OF LIFE

THE earth does not end at its crust. The tops of its mountains and the surfaces of its seas do not define its true circumference. It carries with it on its journey through space a mighty volume of gases known collectively as the air, or atmosphere. However fast the earth flashes, however rapidly it spins, its gravitative force still grips these gases. One would think that as it rushes eighteen miles a second through space, spinning like a dancing dervish, the atmosphere would be swept off it; but, in the first place, there is no friction in space, and, in the second place, gravity is quite strong enough to grip the gases to it.

How high the atmosphere is it is difficult to say. Meteors have been observed in it at a height of two hundred miles, and that is the limit commonly ascribed to it; but the Aurora is visible at heights of from five to six hundred miles, so that there must be some very attenuated gases extending out that far, and no doubt molecules of lighter gases rise higher still and, passing beyond the control of the earth's attractive force, escape into space. It is not so easy, however, as some people think for molecules of gas to escape into space, for it must be remembered that at the outer limits of the atmosphere the molecules are exposed to the paralyzing cold of space.

The air extends not only upwards but downwards: it penetrates for some distance into the ground, and it is found in solution in all natural unboiled water.

Now, what does this great gaseous envelope mean? What is the *raison d'être* of the atmosphere?

The gases of the atmosphere perform most important geological and biological functions. Without them there could be neither animal nor plant life on the globe. All functions of life, motion, assimilation, reproduction, depend on a supply of these gases, and especially on a supply of oxygen. All living things, whether microbes or mastodons, cabbages or kings, fishes or caterpillars, require a conjunction between their corporeal substances and the oxygen of the air. This conjunction is the fundamental fact in the process of respiration, and is of the same nature as combustion; it consists, like combustion, in the wedding of oxygen and carbon and in the production of the gas carbon dioxide. All plants and animals respire in this fashion, and the constant supply of oxygen to the cells of living things keeps going the mechanism of life.

And plants not only breathe the air; they also feed upon it. All living tissues contain carbon, and plants, assisted by sunlight, and by means of the green substance known as chlorophyll, get hold of the carbon dioxide in the atmosphere, tear the carbon from the oxygen, and use it for building up their living matter, or protoplasm. The enormous coal fields consist of carbon extracted from the air by the ancient forests. Wood contains nearly half its weight of carbon.

Animals, again, get the carbon they require by eating the carbon-containing plants. If there were not carbon dioxide in the air, plants could not get material to make their substance, and animals, in turn, could not get material to make theirs.

Not only does the life of man depend on the air, but even if he could live without air his life would be a much poorer thing; for without oxygen there would be no fire, and without fire man might be little better than a savage. Fire with its many consequences has helped to lift man from savagery to civilization. Wisely did the Greek myth relate how a god filched fire from heaven; wisely did the philosopher define man as the fire-making animal. Without air, no fire; without fire, no arts, no trains, no automobiles, no steamers, no telephones, no telegraphs, no telescopes, no microscopes. To the ardent affinity between oxygen and carbon we owe more than we can possibly calculate.

Further, were the carbon dioxide and the oxygen in the atmosphere not in due proportion, and not diluted with nitrogen, the present beneficent results of respiration and combustion would be quite impossible. In pure oxygen, under the ordinary pressure, we should live feverishly and for a short time; in pure carbon dioxide we should suffocate. In pure oxygen a fire could hardly be extinguished; in pure carbon dioxide it could never be kindled. Even were the atmospheric gases mingled in different proportions, the difference would alter the whole vital aspect of the world.

The ameliorative effect of the atmosphere in all weathers

Suppose that man could live and flourish without breath and without fire, even still he could not live without an atmosphere. Except for the air we should be alternately grilled and frozen — grilled all day and frozen all night. The two hundred mile layer of air round the globe acts as a parasol by day and as a blanket by night. It tempers the heat of the sun; it mitigates the cold of the sunless hours. Let us look at these two functions of the atmosphere.

The atmosphere tempers the heat of the sun. The difference between tropical heat and temperate zone heat, between noonday and morning heat, between summer and winter heat, is mainly a matter of atmospheric impediment to the passage of the sun's rays. The more oblique are the rays the greater depth of atmosphere they have to pass through, and the more their passage is impeded. In the tropics the rays of the sun are more vertical than in the temperate zones, hence the tropics are hotter than the temperate zones. At noon the rays of the sun are more vertical than in the morning, hence the noon is warmer than morning. In summer the rays of the sun are more vertical than in winter, hence summer is warmer than winter. It is mainly a matter of atmospheric interference, though, of course, the more oblique the rays, the less concentrated is the heat where they fall.

The interception of the rays of the sun by the atmosphere

In the same way as we ascend, and as the layer of air between us and the sun grows thinner, the sun grows more scorching.

When we examine the colors of the visible solar spectrum, we find dark lines here and there, indicating that certain rays which started from the sun have been absorbed en route. In the invisible spectrum similar lines indicating absorption appear: there are cold streaks amid the infra-red heat waves, and non-actinic streaks amid the ultra-violet actinic rays. Most of the lacunæ, or vacant places, are due to absorption of rays by the atmosphere of the sun, but others are due to the absorption of the rays by the oxygen, and nitrogen, carbon dioxide, and water vapor, of the earth's atmosphere. Tyndall calculated that the atmosphere intercepts about four-tenths of the solar heat during the whole day, and Bunsen and Roscoe calculated that, in passing through the atmosphere, the sun's rays lose about sixty-six per cent of their chemical potency. Every cloud that passes across the sun demonstrates how the atmosphere mitigates the sun's heat; and every photographer knows how much the chemical potency of light varies with the condition of the atmosphere.

Nay, the blue sky itself testifies to the impediment of the atmosphere, for the blue is due chiefly to the dispersion of blue rays by the particles of dust in the atmosphere. Many of these blue rays eventually reach the earth but others no doubt are permanently stopped.

What we should see in the sky if there were no atmosphere

The blue rays, which are at the chemical end of the spectrum, represent little ripples in the ether; and just as little ripples of water may be broken by small stones while big waves roll over them, so these rippling little blue waves of ether are stopped, or reflected, while the larger yellow and red waves mostly roll on. But when the light passes obliquely, and has therefore to pass through a thicker layer of air, not only the blue but also the red rays are dispersed, as we see in the red of the sunsets. Were it not for the atmosphere we should see a blazing bluish sun in a black sky; we should see the stars by day, and we should miss all the glories of the sunset. It is noticeable that at great altitudes the sky becomes a darker blue, and some stars become visible during the daytime.

If the atmosphere were removed, the sun would be intolerably hot. At an altitude of 11,000 feet water exposed in a blackened bottle to the sun boils; and if there were no atmosphere at all the ocean would soon all evaporate away and even the rocks melt.

Tremendous would be the heat by day, and equally tremendous, as we shall see, the cold by night, though perhaps on moonlight nights the sunlight reflected from the moon might raise the temperature a little.

But the sun has more than thermal power; it has mysterious chemical power, and electromagnetic power, and possibly other powers, too. Violet and blue rays hasten the hatching of flies' eggs; they sunburn the skin; they kill many microbes; they *help* chlorine and hydrogen to combine; they hasten the oxidation of oxalic acid and other substances; they blacken some silver salts, and when they fall upon the eyes of animals they cause a quicker absorption of oxygen. These are a few of the chemical things that we know the rays of the sun can do, and no doubt they do many things that we do not know. Certainly they would act more potently were they not enfeebled by the atmosphere. While, if there were no atmosphere, rays that at present do not reach the earth would reach it and produce novel effects.

The atmosphere, then, filters and enfeebles the rays of the sun; and the rays of the sun that now reach us and warm the earth, and make leaves green and cheeks rosy, are *selected* rays. Did all the rays of the sun reach us, the result would be disastrous. More heat, and we might be roasted; more light, and we might be blinded; more chemical rays, and we might be slain like microbes, or completely changed in all our physical habits

So much for the air as a parasol. Let us now regard it in its capacity as a blanket. As we have seen, the air impedes the passage of sun rays to the earth, but even more does it impede the radiation of heat from the earth. During the day the earth is warmed by the sun; and during the night, when the air is cooler, it tends to radiate away its heat. But the heat radiating away is absorbed by the atmosphere, especially by the aqueous vapor and carbon dioxide in the atmosphere, and is radiated back again.

The effect of the aqueous vapor in keeping the earth warm is shown in many ways. It is well known that cloudless nights are much oftener frosty than cloudy nights, and that places with dry climates have a much greater fall of temperature at night than places with moist climates. At high altitudes, also, where the air is dry, there are great diurnal extremes of temperature. At Quito, for instance, 9350 feet above sea-level, the daily variation at some periods of the year is no less than 34° F.

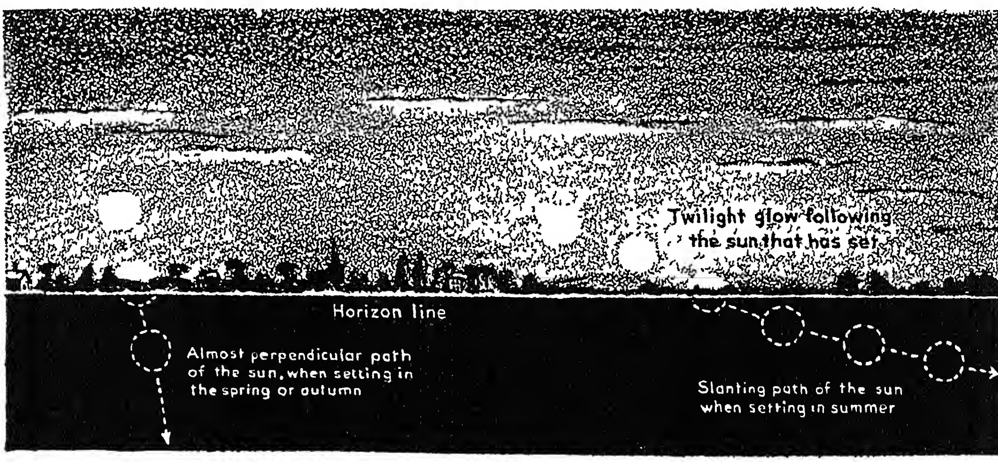
Not only does aqueous vapor prevent the leakage of heat from the earth by absorbing heat and radiating it back, but it contains great stores of latent heat which are given back if the cold be great enough to condense it. Thus the water vapor equivalent to one gallon of water on condensing at 20° C. gives out an amount of heat equivalent to that required to melt 61.2 pounds of ice, or to that required to heat and melt about 26 pounds of cast iron. As vapor contracts and condenses into a cloud, it is an example on a small scale of the contraction and condensation of a gaseous nebula, and the heat given off from the cloud is of the same nature as the heat given off from the contracting sun. Every cloud is to some extent a furnace.

It is interesting to note that the aqueous vapor in the air is in a way an automatic regulating apparatus. As the sun's power increases, more water vapor ascends into the air and at a certain height condenses into cloud and impedes the passage of further heat-rays. As the cold increases, the cloud falls in rain, and the heat-rays have again clear passage.

Great as is the thermal importance of the aqueous vapor, the carbon dioxide in the atmosphere must be considered of almost equal importance. Carbon dioxide is especially opaque to such rays of dark heat as the heated earth radiates towards space. It acts very much like the glass in a hothouse: it transmits the luminous rays of the sun but will not allow the dark rays of heat radiated from the heated earth to radiate away again. So successfully and persistently does it oppose radiation that a very small increase or decrease in the carbon dioxide has very large thermal consequences. The atmosphere contains on the average only .04 per cent by volume of carbon dioxide, yet even the removal of that small quantity would have serious consequences. According to the calculations of Arrhenius, the removal of the carbon dioxide from the atmosphere would lower the temperature of the earth's surface by about 21° C., and this lowering of the temperature of the crust would diminish the amount of water in the atmosphere and thus lead to a further almost equally great fall of temperature.

Arrhenius also calculates that any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4° C., and that if the carbon dioxide were increased fourfold, the temperature would rise by 8° C. Further, a diminution of the carbonic acid percentage would accentuate the temperature differences between the different portions of the earth, while an increase in this percentage would tend to equalize the temperature. Of such thermal value are aqueous vapor and carbon dioxide in retaining the heat that the sun supplies us.

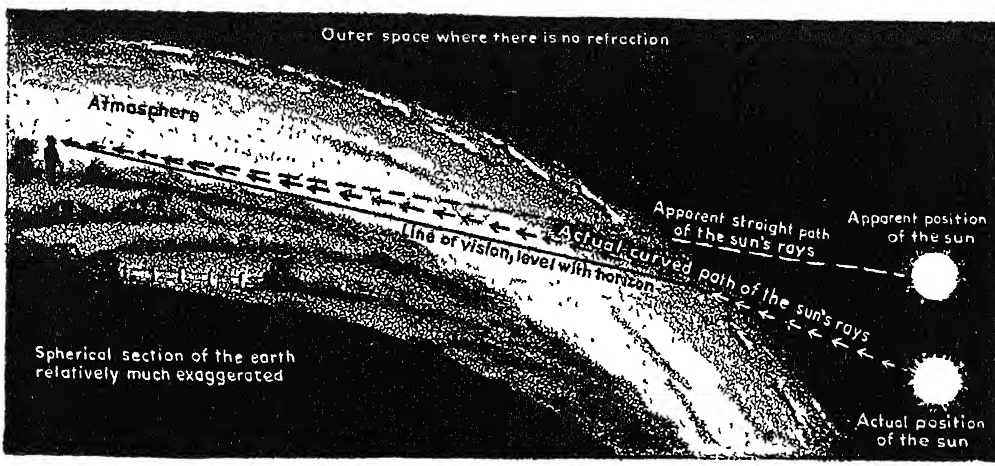
Suppose, then, that all the atmosphere were suddenly removed one morning, what would happen? During the day, as we have seen, the unimpeded heat-rays of the sun would boil away the sea and fill the atmospheric zone with an enormous volume of water vapor, but the moment the sun fell the upper margins of this layer of water vapor would be exposed to the terrible cold of outer space — nearly absolute zero — and the instantaneous result would be tremendous falls all night long of hail and snow, until the whole earth became a great white, frozen ball of ice and snow. Blazing on the snow and ice, the morning sun would melt them everywhere; there would be a thaw, but probably the heat of the sun would not be sufficient to melt and evaporate them all, and the world would assume a permanently frozen aspect, yet by day water would actually boil in icy kettles.



Why twilight is long in June and December and short in March and September

Though the earth has always had an atmosphere, it is possible that some of its glacial and tropical periods were due to alterations in its quality and quantity.

Besides aqueous vapor and carbon dioxide, the dust affects the passage of the sun's and earth's radiations; and in the great volcanic eras, and in the eras of mighty tempests, the dust may have played an important part in modifying the temperature of the earth's surface. These are, perhaps, the most sensational parts the atmosphere plays, but it plays many other parts. It actually increases the length of the day by refracting the rays of the setting sun, so that it still appears above the horizon after it has actually set. On the equator the period of sunlight is increased in this way by only four minutes, but in the higher latitudes the total increase of sunshine thus obtained amounts to hours. It is quite a fashionable thing nowadays to go to the Land of the Midnight Sun; but the midnight sun in such a case is really an optical illusion, for though it *seems* to keep above the horizon, it actually sinks below it.



A diagram explaining why we see the sun after it has set.

Physiologically, the air is indispensable. Not only is it a *sine qua non* of respiration, and thus of all vital processes, but it is the medium of sound-waves. Without air there would be dead, appalling, universal silence. The surges would break silently on the sands and Niagara would fall over its precipices without a sound.

In æsthetic ways, too, air plays a part. It is air-waves that make audible a Beethoven symphony; it is air that carries the causes of rainbows and Northern Lights; it is air, or at least the dust in the air, that gives us the blue sky and the gorgeous sunset hues; and it is also air-dust that gives a softness to the lights and shades and lines of the world. Without atmosphere, all lines would be hard, and all shadows black and uncompromising.

In subtler ways, too, the atmosphere does many unsuspected things. Who would think that it is atmospheric pressure that helps to keep the heads of our thigh-bones in their sockets? Lift the weight of the atmosphere, and we should all wobble about with slightly dislocated thighs. In brief, then, even supposing that we could live without atmosphere, we should be lame, and blind, and deaf, living in a world without chiaroscuro — a world with a blinding sun shining in a black, starry sky — a world alternately frozen and roasted, with pools of boiling water in potholes of ice.

Though several of the planets possess an atmosphere, probably only the earth has that special combination of gases that we know as the air. Marvelous it is, surely, that these few gases should have such momentous consequences, and that they should be found just where they are wanted, and apparently in exactly the quantities required.

For the earth might quite well have lain naked and bare-faced to the stars, and then what an abortion it would have been! Or it might have had a surplus only of oxygen or only of nitrogen, or only of argon, or only of carbon dioxide, and then where would we have been? Well may our wonder be mingled with sentiments of gratitude to the Author of the universe when we contemplate this delicate adjustment of the various constituents of the air; and well may we call science to our help in our desire to know how the gases come to be there so opportunely and what may be their origin and history.

Where did they come from? Were we sure of the nebular hypothesis, the most obvious answer would be that they are the last uncondensed and uncombined portion of the gases of the original nebula. In so far as the earth has this fringe of gases, in so far it is in a nebular condition. At first, according to the nebular theory, the earth was all gases together, but as its heat radiated away the gases became liquids, and the liquids solids. The iron, the silicon and other elements combined and solidified into the rocks, the water vapor condensed into the oceans, and ultimately all the gases were converted into liquids or solids, except the gases now in the air and perhaps some gases at the earth's core. On this theory, "we must regard the atmosphere of any planet at any time as the mere residuum which has been left after all possible combination has taken place", and oxygen, nitrogen, carbon dioxide and water vapor are by-products left over when the rocks were made.

Is this a likely theory? At first sight it seems very likely and, indeed, if we are to accept the nebular hypothesis, this explanation of the atmosphere almost necessarily follows, but when we look into the matter there are many difficulties.

It is quite likely that nitrogen, which is so inactive, might have remained uncombined. But oxygen is among the most active elements and readily unites with almost all the other elements. How then did such large quantities of oxygen remain uncombined during the formative period of the earth's crust?

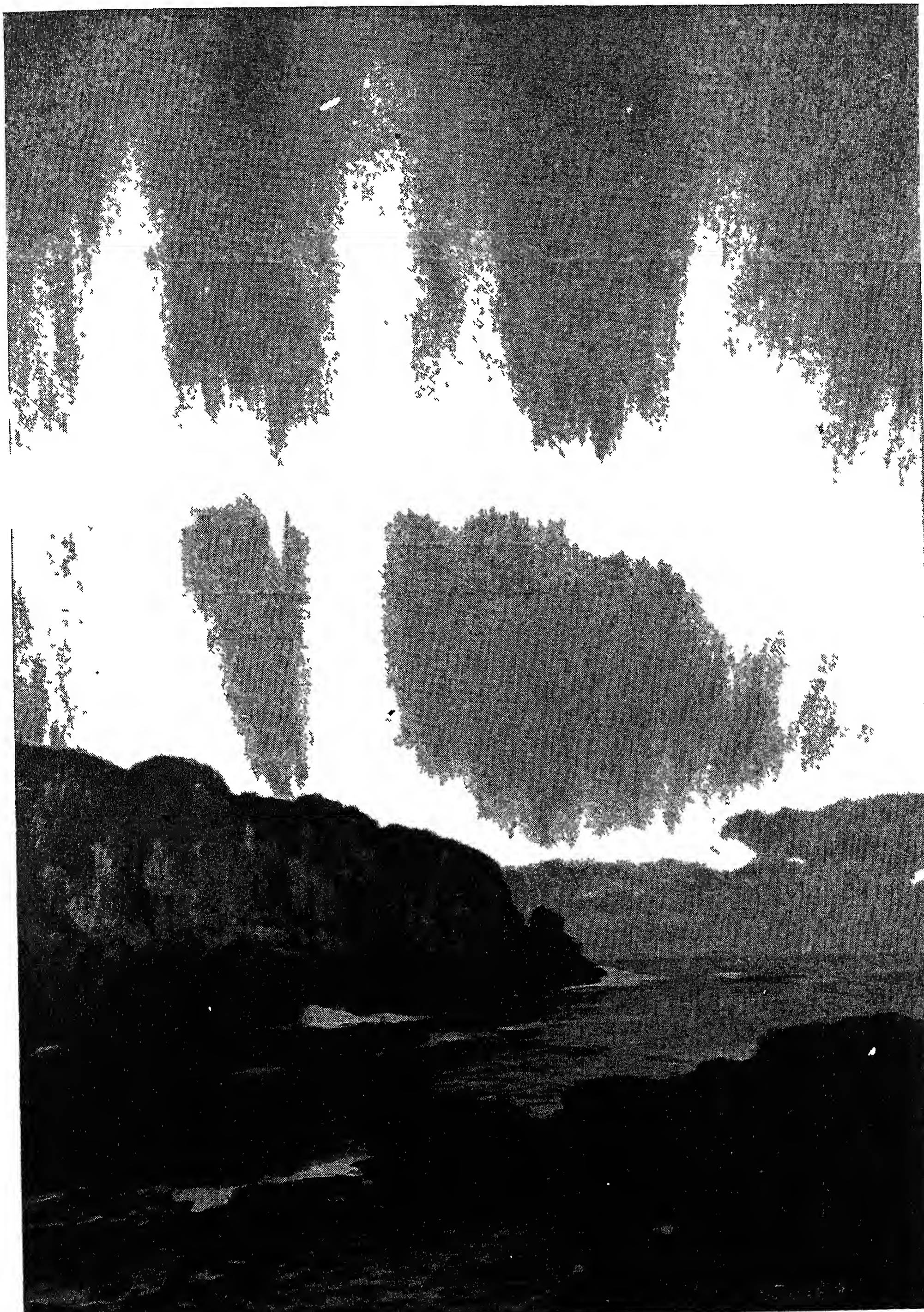
Difficulties of the theory that air is gases left over from solid combinations

Again, on this residual theory all the water in the sea, and all the carbon dioxide and oxygen in the earth's crust supplied to the crust by the atmosphere, must at one time have been in the atmosphere and the water vapor and carbon dioxide still in the air are simply a remnant of the original stock. But this would mean that the atmosphere was once of most tremendous extent. If we were to restore to the atmosphere all the carbon dioxide in the carbonates of the earth's crust, we should have an atmosphere of carbon dioxide more than two hundred times the volume of the present atmosphere. In the lime strata of the Carboniferous epoch alone there is imprisoned six times as much carbon dioxide as is present nowadays in the air. Huge amounts of oxygen, too, might be recovered from the oxidized rocks in the earth's crust

Accordingly, if the atmosphere was a residuum, it must have been a tremendously voluminous residuum — so voluminous that gravity could not possibly have held it. Gravity can just hold with difficulty the present atmosphere, and any additional gases given to the atmosphere would fly away. We cannot, therefore, believe that all the gases that circle and that have circled the world were left over as one immense atmosphere from a primeval fire-mist. In fact, the atmosphere does not seem to fit into the nebular hypothesis.

Let us see what the meteoritic hypothesis can do. According to this theory, as we have seen, the earth grew by an agglomeration of meteoric particles which gathered together under the influence of gravity, and were softened and melted by the heat generated by impact and contraction. At first the globe would be small; and even if there were molecules flying about, it would not have enough gravitative force to gather them around it into an atmosphere, but after the earth attained to about the size of the moon it would begin to collect the flying gases. The first captured would be carbon dioxide, since it has the slowest and heaviest molecules; then oxygen, then nitrogen, and, lastly, water vapor.

FLICKERING CURTAINS OF LIGHT IN THE SKY



The aurora borealis, or northern lights, as seen from Ogunquit, Maine; from a well-known painting by Harold Russell Butler. The northern lights are among the most fascinating of natural spectacles. They are caused by electrically charged particles from the sun which collide with the atmosphere.

But even if we accept this theory of the capture of gases it does not get us out of the difficulty, for the earth has not gravitative force sufficient to capture *all* the aqueous vapor now condensed in the sea, and *all* the carbon and oxygen now in the earth's crust, but evidently formerly in the atmosphere. There seems only one way of surmounting it and of explaining such a large volume of atmospheric gases, and that is by supposing that the greater part of the atmosphere and of the aqueous vapor now in the sea were originally built into the earth's crust. We find that meteoric stones always contain gases in their pores, and if the earth were built up of such meteoric material it must have contained the meteoric gases. Again, we find that lavas and molten masses, however hot, may hold gases in solution, and that if they solidify under pressure they will retain the gases in their substance, much as a bottle of frozen champagne would retain the gas in the ice. The gases found in meteoric stones are chiefly hydrogen, carbon dioxide, carbon monoxide, marsh gas and nitrogen. And supposing these same gases were inclosed in the solidifying rocks, the hydrogen would probably take oxygen from the ferric oxide so common in the earth, and thus form water. It is probable that the carbon monoxide would change into carbon dioxide, and that the marsh gas would disappear. We would thus have left three of the chief gases of the atmosphere — nitrogen, carbon dioxide, and water vapor.

How about oxygen? Oxygen might be produced under certain conditions by the ferric oxide. Thus we should have all the gases of the atmosphere in the bowels of the earth either shut into the solidified rock or in solution in molten masses. Granted that they were there, it is easy to see how they could escape to the surface through volcanoes and in other ways, and thus form the atmosphere. On this hypothesis, *all* the atmospheric gases would not be in evidence *at once;* they would escape to the surface, and enter into combination in the crust *pari passu.* As quickly, for instance, as the carbon dioxide was buried in the earth as coal it would be replaced by volcanoes.

Volcanoes as the source of one constituent of the air

A certain amount, then, of the atmospheric gases may have been captured from space, or a certain amount may have been left over from the rocky material of the world, but the greater bulk of the gas must have been extracted from the crust itself, to enter again into solid combinations with its surface layer.

Probably all the carbon dioxide was belched forth by volcanoes. Even in the present day of comparative volcanic quietude vast volumes of carbon dioxide are given forth by volcanoes. According to Boussingault, the volcano of Cotopaxi gives off as much carbon dioxide as the whole city of Paris, and a few such volcanoes blazing for a few hundred thousand years would eventually provide the .04 per cent of carbon dioxide in the atmosphere.

Probable changes in the atmosphere and in the accompanying forms of animal life

It is probable, indeed, that at first the atmosphere of the earth consisted almost of carbon dioxide and nitrogen, and it is quite likely that oxygen was added to the air by the vital activities of the first green plants, and that this was its main source. In this primitive atmosphere of carbon dioxide green plants would flourish exceedingly; and when we consider that there must have been tropical heat and abundant aqueous vapor, we can well understand the luxuriance of the vegetation in the Carboniferous period. When the primeval jungles had manufactured enough oxygen to supply large animals, large animals began to appear. At first, naturally, only animals with sluggish natures could live, and no doubt the reptiles of the Paleozoic and Mesozoic eras were qualified to live in a muggy, carbon-dioxide-laden atmosphere, but as the oxygen accumulated and the carbon dioxide was locked up, the atmosphere became more fitted for active animals, and more active animals, birds and mammals, appeared; for, after all, the chemical processes of life are mainly a matter of oxidation. When we look at the moon we find that it has been the seat of furious activities,

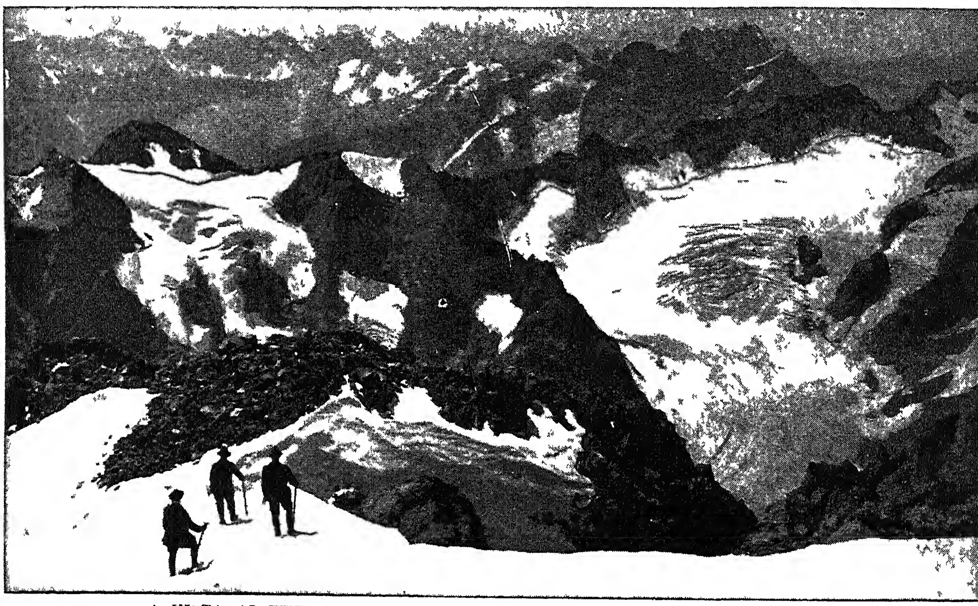
THE SMOKING CRATER OF COTOPAXI, THE HIGHEST ACTIVE VOLCANO IN THE WORLD

The crater of this volcano in the Andes of Ecuador is 2500 feet in diameter, and sends out into the atmosphere as much carbon dioxide as the city of Paris.

probably of volcanic character, and hence, if it had only been big enough to hold back volcanic gases, it, too, might have acquired an ocean and an atmosphere which would have fitted it for habitation by animals and plants Without an atmosphere our world would be dead as the moon and almost as dry Possibly some volcanic gases lost by the moon were captured by the earth.

Seeing that the atmosphere has probably altered in the past, it is natural to inquire whether it is still altering, and whether there is likely to be any further change in its size or in the proportion of its gases. On the face of the earth today there is great gaseous activity. Men, beasts, plants, volcanoes, fires, are all giving and taking gases. Is the proportion of carbon dioxide increasing or decreasing? It is a question of momentous importance to the whole human race, for the physical well-being of man may depend on the stimulus of a little more or a little less oxygen. If the oxygen be reduced, man may become as lethargic as a lizard; and if it be increased, his activities may be quickened proportionately.

The question cannot be confidently answered; we have not enough data. We know that men, and animals, and decay in vegetation, and volcanoes, and mineral springs and fires throw an enormous amount of carbon dioxide into the air. We know, on the other hand, that a single acre of green ground is sufficient to remove the carbon dioxide discharged by twelve or thirteen persons, and to restore to the atmosphere the oxygen the persons retain. Whether, however, plant life is sufficient to break up *all* the carbon dioxide annually added to the atmosphere is a moot question. If the carbon dioxide be actually increasing, it might be a serious matter for the animals of the world; but the more carbon dioxide the air contains, the more will green plants consume, and that must do something to counteract any excessive production of carbon dioxide. But the great regulator of the amount of carbon dioxide in the air is the sea. The sea contains twenty-seven times as much carbon dioxide as the air. If a certain additional amount of carbon dioxide is given to the air, a large proportion of it is at once seized by the sea. For this reason it would require an enormous surplus production of carbon dioxide to produce any marked effect on the earth's atmosphere; and altogether we may be confident that green plants and the blue sea will protect us from any deleterious increase of carbon dioxide.


A VISTA OF THE ALPS, WHERE THE ATMOSPHERE IS RARE AND CLEAR
This photograph, by Mr Donald McLeish, was taken from the summit of Mount Pelvoux, 12,973 feet high.

WHERE DARWINISM HALTS

It Does Not See Life Finding by Inward Impulsion a Highway Up to the Mind of Man

PSYCHICAL FORCE IN PHYSICAL FORMS

DARWIN sleeps in Westminster Abbey, as he should. All men who honor noble qualities of mind and temper honor him. His services to biology are immense and indispensable. Yet, while we "praise famous men", we must pass on, for we are alive and life ever presses forward. That, indeed, is the leading idea of Henri Bergson, who carried on the theory of evolution further than any of his predecessors. Before we pass to the scientific detail of the great problems of heredity and variation, we must complete our history of the idea of evolution by giving due discussion to what this thinker has taught us

We have accepted the mechanical laws of natural selection, which is ever at work destroying the least adapted to the conditions of life We must further accept the truth that life, in all its evolution, never transcends physical laws No living being creates or destroys an iota of energy or an atom of matter. The processes that occur within it obey all the laws of physics and chemistry. The living being is demonstrably an internal combustion engine turning the chemical energy of carbon, hydrogen and oxygen into motion, just like the engines which man makes. We speak of organic chemistry, physiological chemistry, bio-chemistry, but we know that these are all a part of chemistry as a whole, and break none of its laws. Life and the evolution of life, whatever their ultimate explanation be, work through and exist in the material world, and obey its rules. It is a great achievement of science to have established these truths once and for all. Nothing taught us by Bergson, or by any subsequent thinker, will shake them.

But we have been apt to make the stupendous mistake of supposing that, because the living being obeys physical laws in its working, it is simply their product, and nothing more The truth is that the mechanical-materialist, physico-chemical theory of life has confounded the mechanism of life with the nature and essence of life Of course life uses mechanism, as the poet or the musician does; life even *makes* the mechanism it *uses*, and obeys the laws of physics and chemistry in its uses, just as the musician obeys them in his instruments But life and the musician still remain to be reckoned with.

There is no gainsaying the fact that the theories of evolution which we have already studied are essentially mechanical, and they depend upon a mechanical theory of life. Natural selection, for instance, is essentially a mechanical process, which therefore applies just as well to atoms as to living things. We have already learned that the theory of natural selection assumes the production of *chance* variations, in all directions, some favorable to survival, others unfavorable, and the favorable are chosen. But it is a cardinal part of this mechanical theory of evolution that the variations are at random, essentially accidental, and that they exhibit and flow from no purpose, intention, or design, behind things and working through them.

The evolution of man, and his mind, feelings and ideals is essentially, on the theory of natural selection, the consequence of the automatic survival of chance variations in living organisms, from the lowest upwards — in short, the making of man is a chapter of accidents.

Thus, if evolution, as understood in the nineteenth century, did anything at all, it banished *design* from the living world. We might incline to say that the eye was made, or evolved, *in order to* see, limbs in order to move, and so on; but that was only apparent. We were taught that the eye, the limb, the brain, were products of random variation, which owed their survival and perpetuation to their "survival value". At all costs, we were required to exclude from our description of the living world, and all its parts, any terms or ideas which involved the suggestion of purpose, design, "final causes", or teleology, to quote the classical phrases for this idea. The doctrine of Darwin was set up as established by science and as demonstrably discrediting the view, held from all time, expressed in 1802 in Archdeacon Paley's famous "Natural Theology; or Evidence of the Existence and Attributes of the Deity". This book gave fine expression to the idea that the facts of nature show mind and design behind them—whence the argument may be made for an Almighty Mind, and thus we have a "natural theology".

Return of the ideas of design and purpose to physical science

Paley said that if, walking on a heath, we found a watch and examined it, we could not resist the inference that there must have been a watchmaker, so clear is the evidence of design in it. But living things, he argued, show evidence of design, as the watch does, and require the same inference.

The opposition between this view and Darwin's is absolute. Paley points to the eye, which seems to be crammed with evidence of design. Darwinism argues that its features are the product of random variation, fixed by natural selection. According, therefore, to what we may call the standard scientific teaching of today, which has been spread broadcast by the enemies of religion in especial, we are totally to exclude from our interpretation of the living world anything of design or purpose — an exclusion which, evidently, has serious consequences for the theology that found evidence of a Designer in nature, according to Paley's argument, so long accepted as adequate by the whole modern religious world.

But, in point of fact, we cannot describe the world of life, and the features of its inhabitants, without using terms that involve the idea of purpose. We cannot describe the lens of the eye, and the muscle which alters its shape, for near or for distant vision, without saying what we have just said, that they exist *for* near or *for* distant vision. To describe the anatomy and physiology of any living thing without using such language is simply not to describe them. The most convinced champions of the idea that there is no design or purpose in living things *have* to use language which implies it when they begin to describe them.

The inadequacy of any theory that cannot account for mind

We find mind associated with life, and here is a complication for our materialist-mechanical theory. We study the chemical mechanism of the living body, and find that it involves the use of ferments. All manner of things happen, in the digestive canal of man or any creature that has a digestive canal, or indeed in the cell we call an amœba that has no digestive canal, which depend upon fermentation; and when we discover that *all* the essential processes of a living organism depend upon fermentation, even that the development of the adult depends upon the presence of ferments, or substances preliminary to ferments, in the germ cells, we incline to frame the bold and engaging generalization that "Life is a series of fermentations". But mind is to be explained also. No theory of life which does not explain its psychical side is adequate. This psychical side is not a late accident. Mr. Francis Darwin has found evidence of sensation in plants. Minute microscopic organisms, animal or vegetable, when closely examined, are found to exhibit choice, to try and to learn. They *behave*. Indeed, the evolutionist is bound to expect to find traces of mind in low forms of life, and such traces, and more than traces, exist.

Now it was all very well to look at the physical aspect of a living thing, an amœba or a man, to follow digestion, respiration, development even, and perhaps reproduction also, and say that "life is a series of fermentations".

When perfect mechanical adjustment is reached life makes further adjustments

But the proposition "Mind is a series of fermentations" is silly, and involves the conclusion that our assertion about life was one only about its mechanism.

It follows that we require a theory of evolution which shall take into account the psychical aspect of life, and not the physical aspect merely. We have far more to account for than our current theories recognize. Take, for instance, adaptation. Paley, speaking for a great host, sees in adaptation, as a thousand species illustrate it, palpable proof of design. Darwinism and mechanical evolution see in it the action of natural selection, which permits the survival of the best-adapted. But even supposing that this theory told us anything of the origin of the best-adapted, as we know it does not, there are facts which it does not account for. Life is not merely adaptation — even if "merely" be the right word. We have recognized and have insisted upon adaptation so much that we have ignored a most tremendous fact. Herbert Spencer's valuable and suggestive definition of life was that it is "the continuous adjustment of internal to external relations." That, of course, is no real definition — since we are entitled to ask adjustment *of what?* — but it is a description of a great fact of life. Its result is adaptation. Now let us suppose that the "external relations" remain fixed, and the living thing adjusts its "internal relations" to them. Life, on this definition, should stay there. The adapted species should persist.

But the stupendous fact which this description of life ignores is that life does *not* stop when it has achieved adaptation, the perfect adjustment of internal to external relations. The amœba is adapted, and the alga and the sponge and the oyster. Life produces these adaptations, but it is not satisfied. Our theory does not begin to account for the continued production of new forms of life, higher, more complicated, more delicate, by no means necessarily better adapted. Once adaptation is achieved this continued process of innovation is unaccountable on any existing theory of evolution or definition of life.

Is there not an aim purposive and psychical behind all evolution?

The failure of our theories, their ludicrous inadequacy to explain the facts, sets us thinking again, as we had forgotten to do. "Hypotheses," said Goethe, "are the cradle songs with which the teacher lulls his pupils to sleep." We survey the world of life and the evident course of evolution. We see that it is a *positive* thing; to account for it by a negation like natural selection, which explains the absent but not the present, is simply to be muddle-headed. And we may remember that one of the world's greatest poets described the living process in his own way, about a century ago. For, in his "Adonaïs", Shelley bids us see how

> The one Spirit's plastic stress
> Sweeps through the dull, dense world, compelling there
> All new successions to the forms they wear.

Here is the idea of life as something purposive, and therefore psychical, behind matter, striving through matter to multiply, to magnify, to intensify itself.

The consciousness of man the intensest form that life has yet reached

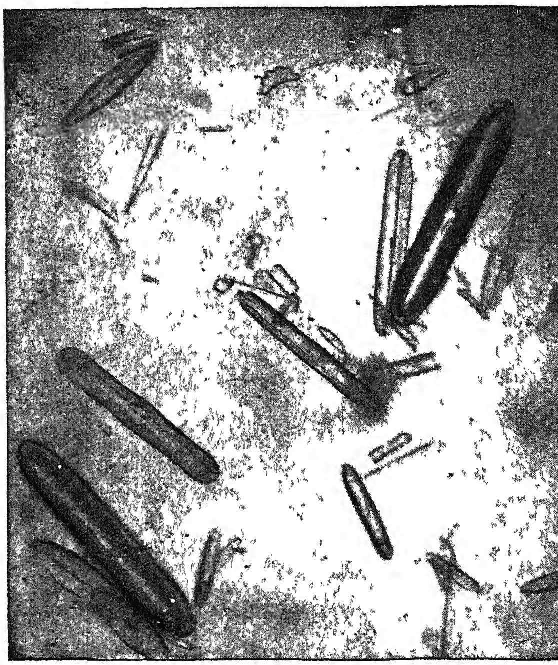
The theory implied in these lines from Shelley is exactly that of Bergson, that life is a psychical thing, tending to act on and inform inert matter, and "compelling there all new successions to the forms they wear". The poet's lines express to a nicety what the French thinker describes as the *élan*, the thrust, the impetus, the "plastic stress", indeed, of life. Progress is essentially the emergence and increasing dominance of mind in the living world and it springs from the inherent tendency of life to express itself in ever intenser forms — the consciousness and self-consciousness of man being the intensest expression of life we can conceive.

We must make a fresh start, then, with our theory of evolution, beginning with a conception of life as "of the psychological order", as something which, like our own selves (who are its highest expression), has purpose and intention, goes on, is never satisfied, "never is but always to be blest".

It is essentially creative, then, as Henri Bergson expresses in his phrase "Creative Evolution", and as Shelley expressed by the word "plastic". Like any human practitioner of the "plastic arts", it makes models which are worthless and are destroyed, but it also makes good models which persist. Yet it is never content, as if it were merely "the continuous adjustment of internal to external manifestations". As Bergson says: "Life in general is mobility itself; particular manifestations of life accept this mobility reluctantly, and constantly lag behind It is always going ahead; they want to mark time" Is it not so with human institutions made by life acting through great men?

Hence the individual living thing, as a manifestation and vehicle of life — the onward "is above all a thoroughfare", even though too often "what was to have been a thoroughfare has become a terminus". The reader will observe that these phrases of Bergson's exactly consort with what we have previously argued as to the construction of the individual essentially for parenthood, and with Weismann's view as to the essential relation between the individual and the race — between the particular manifestation of life, and life itself. Are we not now, perhaps, on the way to some view of life which will explain for us the *origin of species*, that central problem of evolution, as to which Darwin's masterpiece told us nothing at all? It must be a view which conceives life as trying, as making efforts; and, as evolution maintains that man is part of the living world, our view must explain man with some greater adequacy than the theory of adaptation, and the "continuous adjustment of internal to external relations", when applied to, let us say, the men who leave their comfortable homes to find the poles.

But surely the view of evolution which these arguments suggest is not entirely new. Have we not heard something like it before? Indeed we have, in the teaching of Lamarck That great pioneer whose work is, unfortunately, still far too little appreciated, taught that living beings develop and modify their powers and their structure in consequence of their effort. Function comes first — life comes first — and develops structure for its purposes. Many neo-Lamarckians today follow their master in this respect. Yet how limited the action of effort and purpose, thus understood, must be! As Bergson says: "If this cause is nothing but the conscious effort of the individual, it cannot operate in more than a restricted number of cases — at most in the animal kingdom, and not at all in the vegetable kingdom. Even in animals it will act only on points which are under the direct or indirect control of the will." Hence, as he argues — and the reader will see how our theory of life can enlarge the idea of Lamarck so as to include all living forms — "A hereditary change in a definite direction — such as the evolution of the eye — which continues to accumulate and add to itself so as to build up a more and more complex machine, must certainly be related to some sort of effort, but to an effort of far greater depth than the individual effort, far

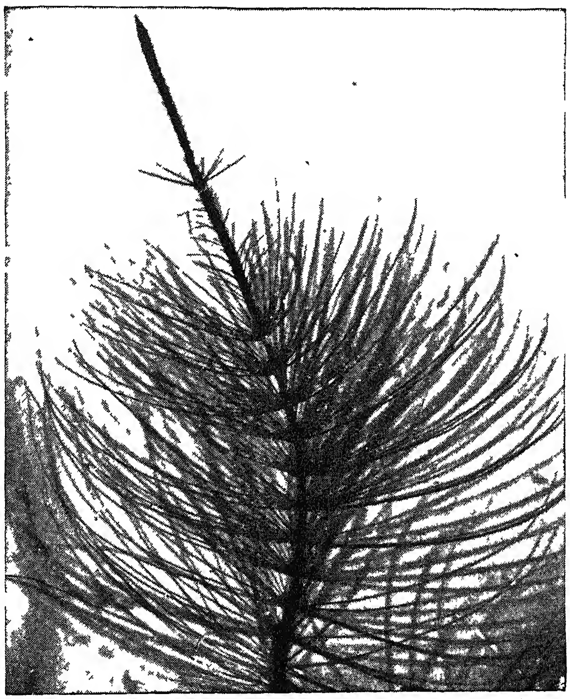


INTELLIGENCE IN THE LOWEST TYPES OF PLANTS

These minute, boat shaped diatoms, without any visible means of propulsion, glide slowly in a straight line, and should anything obstruct their passage they retreat apparently on the same straight tract, often repeating the movement several times, as if unconvinced that the path was unpassable

more independent of circumstances, an effort common to most representatives of the same species, inherent in the germs they bear rather than in their substance alone, an effort thereby assured of being passed on to their descendants."

Thus, as we see, we have returned to the idea of the *élan vital*, the original impetus or thrust or effort of life, a thing essentially psychical, which passes from one generation of germ cells to the next, through the developed individuals that bear them, and that is the *fundamental cause of true variations* This is Bergson's theory, expressing Lamarck's idea, but enlarging it so as to apply to all living forms, and teaching us that the effort which we easily see in animals, though not in plants, is really only the most intense expression of the original effort of life, which is in some degree in all living creatures. And if we duly weigh and consider this theory of Bergson we shall see that it should more properly be called the theory of Shelley, who gave it exact and scientific as well as poetic expression in the year 1821. This is one more instance of the triumph of poetic insight.



DESIGN IN NATURE — ONE OF THE ANTENNÆ OF A GNAT HIGHLY MAGNIFIED

The fundamental cause of true variations, then, is the "plastic stress" of the "one spirit" which we call life, which, according to Bergson, is, "above all, a tendency to act on inert matter," and which, as Shelley said, "sweeps through the dull, dense world, compelling there all new successions to the forms they wear." Whatever we shall hereafter learn from Mendel and Bateson of the mechanism and detail of heredity and variation, we must retain this great idea, which expresses the causation of variations, *and therefore of organic evolution,* which, as we know, absolutely depends upon the production of variations

Two great questions remain, each of which has been dealt with by Bergson in masterly fashion. First, we must try to sketch out the lines along which the *élan vital* has worked and expressed itself, not least with reference to the question of man's destiny; and, second, we must go back to the old idea of a plan given beforehand which evolution is simply realizing, and see why Bergson is entitled to argue that the new theory transcends altogether the old doctrine of a preconceived plan.

We have only to look at the living world to see that life has adopted various methods of expressing itself. We can trace in the vegetable world characters which somewhat pertain to animals and conversely. We can trace signs of intelligence in animals and of instinct in man. But, on the whole, there are very evidently divergent directions in which life has evolved, and a general survey of the living world displays these to us at once.

The great point is that we are not to look at them, as we have done hitherto, as successive, but as divergent, each being an expression of the original characteristics of life. Here are Bergson's own words — the italics are his:

"Vegetable torpor, instinct and intelligence — these, then, are the elements that coincided in the vital impulsion common to plants and animals, and which, in the course of a development in which they were made

manifest in the most unforeseen forms, have been dissociated by the very fact of their growth. *The cardinal error which, from Aristotle onwards, has vitiated most of the philosophies of Nature is to see, in vegetable, instinctive, and rational life, three successive degrees of the development of one and the same tendency, whereas they are three divergent directions of an activity that has split up as it grew.*"

What is meant by "vegetable torpor" is quite evident. Plants are expressions of life asleep, so to say; not dead, any more than a sleeping animal is dead, but yet torpid and tending towards immobility, "the

L. W. Brownell

THESE PITCHER PLANTS DEVOUR INSECTS

The leaves hold a liquid that contains digestive substances. Insects trapped in the leaves are digested and absorbed.

animal, on the contrary, becoming more and more awake and marching on to the conquest of a nervous system". Some writers have argued that it is the thick and rigid cellulose membrane of the vegetable cell that has shut it off from most possibilities of sensation, and involved its renunciation of consciousness.

Animal life has apparently been threatened in the same way. Early animals were imprisoned, too; the arthropods, or joint-footed invertebrates, tended to form rigid cases for themselves. The earliest vertebrates, the primitive fishes, had hard, bony sheaths. But fortunately both arthropods and vertebrates escaped; the many forms remain today to show us how life might have remained at this humble level but for its inexhaustible impetus. The insects escaped from the arthropods, and the later fishes escaped. And if we trace these two forms we find in them the two great directions, instinctive and intelligent, in which life has evolved in the animal world. In each a nervous system appears and is developed in high degree. We can best judge of these two directions by looking at the most successful forms which life has taken in each. As regards the vertebrates and the line of intelligence, there is no doubt about man's dominance. He claims the entire earth for his domain, and is therefore the most successful form. His distinguishing mark is the unique development of intelligence in him.

If we apply similar reasoning to the insects there is no doubt either. Evolution in them (evolution of invertebrates generally) reaches its culminating point in those called the hymenoptera — the ants, wasps and bees — just as evolution in the vertebrates reaches its culminating point in man. Hence, in Bergson's words: "Since instinct is nowhere so developed as in the insect world, and in no group of insects so marvellously as in the hymenoptera, it may be said that the whole evolution of the animal kingdom, apart from retrogressions towards vegetative life, has taken place on two divergent paths, one of which led to instinct and the other to intelligence." But just as rudiments of instinctive and even intelligent behavior can be observed in plants, and just as animals are in constant danger of being drawn aside to the vegetative life, so instinct and intelligence tend still to cling together in some degree.

Thus, in almost all the vertebrates, though intelligence is there, instinct is the basis of their psychical activity, but intelligence tries to perform as many variations as possible on the instinct it would fain dispense with. "Intelligence gains complete self-possession only in man, and this triumph is attested by the very insufficiency of the natural means at man's disposal for defense against his enemies, against cold and hunger. This insufficiency, when we strive to fathom its significance, acquires

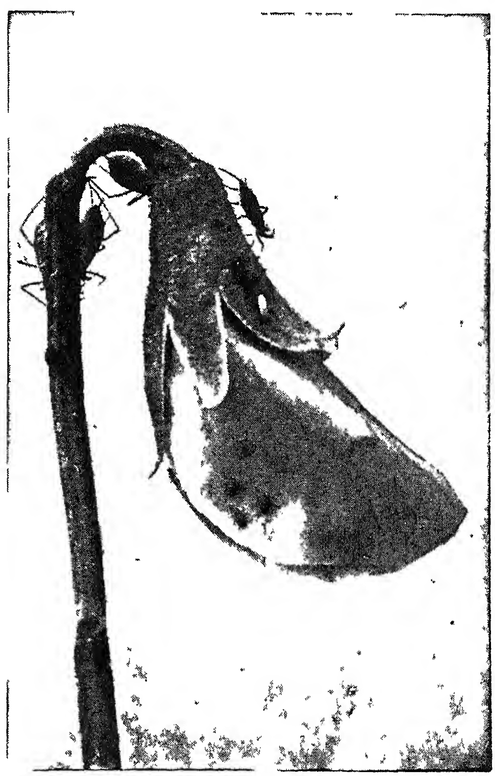
the value of a prehistoric document; it is the final leave-taking between intelligence and instinct. But it is no less true that nature must have hesitated between two modes of psychical activity — one assured of immediate success, but limited in its effects; the other hazardous, but whose conquests, if it should reach independence, might be extended indefinitely. Here, again, then, the greatest success was achieved on the side of the greatest risk."

Thus, life has taken many blind alleys, but only two or three highways; and of these, only one — that which leads through the vertebrates up to man — has been wide enough to allow free passage to the full breath of life. Only man the unlimited is on the open road. The reader will observe the exact consonance between this general theory of evolution and the characteristic facts of the body of man, which have been discussed in another section.

Now let us compare our conclusion with the alternative views which we have already referred to — the mechanical view, based upon the laws of chance, and the view that evolution has followed a plan. We must reject the first, and all the methods which assume its truth. As Bergson says: "Organic creation, the evolutionary phenomena which properly constitute life, we cannot in any way subject to a mathematical treatment." This conclusion of the philosopher goes far to explain what has long puzzled the critics of "biometry", which has reached so many confident conclusions, but never one that further study has confirmed. The simple truth is that life is creative, and therefore immeasurable.

But what of the old idea of design — of evolution as simply conforming to a plan? The new theory, which utterly rejects the mechanical view, does not wholly reject this view, because it recognizes the palpable evidences of design, in which the living body is far richer than any watch. But there is a very great difference between the old view and the new one. Just because life is creative, the direction of its action is not predetermined. It has purpose and intention, but no ready-made plan. It is so with the products of life.

A man sits down to create or produce a play called "Hamlet". It is not evolved by "natural selection", but by conscious purpose. But yet it is not merely the realization of a plan. If Shakespeare had the complete plan when he sat down, then he would have produced "Hamlet" before he produced it, which is absurd. It is so with every creative product of man, or of Life, which includes man. It aims at "more life and fuller", at greater intensity, greater success, but it is a creator, not an artisan.



ANIMALS TENDING TOWARDS VEGETABLE LIFE

The green-flies or blight so familiar on plants may represent animals that are being drawn aside to vegetable life. The greater number are wingless and inactive, and their methods of reproduction are reactionary.

"Hence the unforeseeable variety of forms which life, in evolving, sows along its path." A plan is given in advance, but to survey the amazing variety of the forms of life is to see that evolution is a creation unceasingly renewed, its future overflows its present, and transcends comprehension or prediction by the intellect of man, which is itself only one of the products of life. In Bergson's magnificent words:

"We shall certainly never witness the detailed accomplishment of a plan. Nature is more and better than a plan in course of realization. A plan is a term assigned to a labor; it closes the future whose form it indicates. Before the evolution of life, on the contrary, the portals of the future remain wide open. It is a creation that goes on forever in virtue of an initial movement."

This is by no means all we have to say of Bergson; he will dominate our thinking for many decades to come. Meanwhile his work prepares us for our further studies, as to the evolution of the mental and moral attributes of man—so hopeless of inclusion in the mechanical theory of evolution; and also in regard to the study of variation, and the production of new forms of life. We shall find that adaptation has been much exaggerated in the last half century, and that the Mendelian study of inheritance provides us with plenty of new forms which show no superiority of adaptation, but are *tolerated* (as Professor Bateson has put it) by natural selection, and owe their existence to the "plastic stress" of life.

Meanwhile, we conclude by observing that science and philosophy are now evidently returning to the celebrated doctrine called Vitalism, which declared, a century ago, that life is an entity, not an abstraction, and we have seen cause to regard life as a psychical entity, to be included under Mind in our catalogue of the Universe. The best science and philosophy of the coming years are sweeping onward to Vitalism again, old but new. So true is it that knowledge grows not in a straight line, but in a mighty spiral. Those who crawl below, and do not care, may say that it merely retraces its steps, but they who will follow and further its flight know that the spiral ascends.